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NOISE LEVELS ON AIRCRAFT-CARRIER FLIGHT DECKS, AND THEIR EFFECTS

Updated measurements at NATC and aboard USS KITTY HAWK show degradation of speech communications and risk of deafness to personnel

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13 ABSTRACT

Measurements were made of noise levels produced by four aircraft during pilot qualification exercises aboard the flight deck of USS KITTY HAWK. These measurements, on both the A- and C-frequency weighting networks, were augmented by calculations of speech-interference levels made later from tape recordings. These data were compared to similar measurements made at the Naval Air Test Center at Patuxent River, Md., and interpreted in terms of deafness risk and interference with speech communications. The levels measured on the carrier showed large amounts of low-frequency energy (at octaves centered at 62 and 125 Hz) not present in the data taken ashore; this variation is ascribed to the presence of blast deflectors on the carrier and to the effects of strong wind across the deck and the measuring microphone in its wind-screen. The noise levels measured are shown to severely degrade speech communications and to present a risk of deafness to personnel.

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PROBLEM

Measure the noise levels produced by aircraft landing on and taking off from flight decks of aircraft carriers. Assess these levels in terms of (1) the hearing hazards they present to personnel exposed to them for various periods of time, with varying degrees of ear protection, and (2) the extent to which they degrade speech communication.

RESULTS

1. Pre-launch noise measurements of F4 and A4 aircraft operating off USS KITTY HAWK and of F4, A4, A5, and A6 aircraft in ground tests at the Naval Air Test Center show levels at manned positions (50 feet at 60°) between 122 and 137 dBA at military power, and up to 10 dB greater when the afterburner is operating.

2. When noise exposures were predicated on a 12-hour cyclic air operation, hearing hazards were predicted, even when current ear-protection devices were utilized.

3. Direct observation together with calculation of speech-interference levels indicated significant decrement in voice communication under high-noise conditions.

RECOMMENDATIONS

1. Take immediate steps to correct the problem, first by acquainting designers, and administrative and medical and operating personnel, with the hazards inherent in high noise. Require wider distribution and better maintenance of protective equipment, and conduct annual audiometric tests on flight-deck personnel.

2. At the noisier locations, improve hearing protectors and provide better noise-cancelling microphones or microphone noise shields.

3. In future aircraft design and/or flight-deck operations, consider noise reduction a major objective.

4. Perform investigations on the effects of wind- and blast-deflector-generated noises on human performance.

ADMINISTRATIVE INFORMATION

Work was performed under SF 14 224 001, Task 4956 (NELC B505) by members of the Human Factors Technology Division during the period 1 July – 31 December 1970. The report was approved for publication 30 April 1971.

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INTRODUCTION

There is probably no harsher noise environment in which people must perform complex and vital jobs than on the flight deck of an aircraft carrier operating with multi-engine, high-performance jet aircraft. The high noise levels not only degrade speech communication but present a risk of deafness or hearing loss to the personnel exposed to them for various periods of time. Precautions against these hazards include hearing-protective devices for personnel, and specially designed flight-deck radios.

The primary objective of the study reported here was to update past noise-level measurements on aircraft to include some of the newer jet aircraft and to interpret these measured levels and the periods over which personnel are exposed to them in terms of speech interference and hearing damage. In making the measurements, special note was taken of the proximity of personnel to the noise sources.

A secondary objective is to study the discrepancies between the data produced by measurements made on land and those made aboard CVA's (where blast deflectors and approximately 30 knots of wind across the bow may affect the sound levels).

The study involved measurement of noise levels (1) during a carrier-qualification (CARQUAL) operation on USS KITTY HAWK[1] and (2) at the Naval Air Test Center at Patuxent River.[2-5] (See list of references at end of report.) The aircraft involved were an A4 Skyhawk, an RA5 Vigilante, an A6 Intruder, and an F4 Phantom. The data obtained are presented in the following sections.

THE SHIPBOARD ENVIRONMENT

Before presenting and analyzing the measurements, a brief description of the operational situation on a carrier flight deck will be helpful in understanding the nature of the noise problem it presents. Figures 1 through 6 are photographs of men engaged in representative tasks involved in launching and recovery of aircraft.

Figure 1A shows an A4 being taxied along the deck in a slight cross wind. Note personnel hanging onto the wing and riding along to help stabilize the aircraft. Figure 1B shows a crash and salvage crew standing by an A4 which has just been released from the arresting-gear wire.

Figure 2 shows an RA5 (A) being launched with afterburners, and (B) being recovered. In both cases deck personnel are within very close range. In the afterburner pass-by, noise levels reach or exceed 145 dB.

Figure 3 shows an A6 being launched from the waist catapults on the angled deck. Note a Director signaling another pilot to taxi his aircraft along the deck.

In figure 4, the bridle crew is seen preparing to hook up an F4 to the catapult; in another view, the F4 is bridled into place and is being handed over by a Director to the Catapult Officer.

Occasionally these operations do not go well. Figure 5A shows a whole contingent of plane pushers who have run from positions in catwalks, around the island, or from the relative safety of positions midway between and slightly forward of the catapults (fig. 5B) to push a downed RA5 from off a catapult.

Figure 6 shows a pilot with his flight helmet off trying to talk face-to-face with a Director.

A.

B.

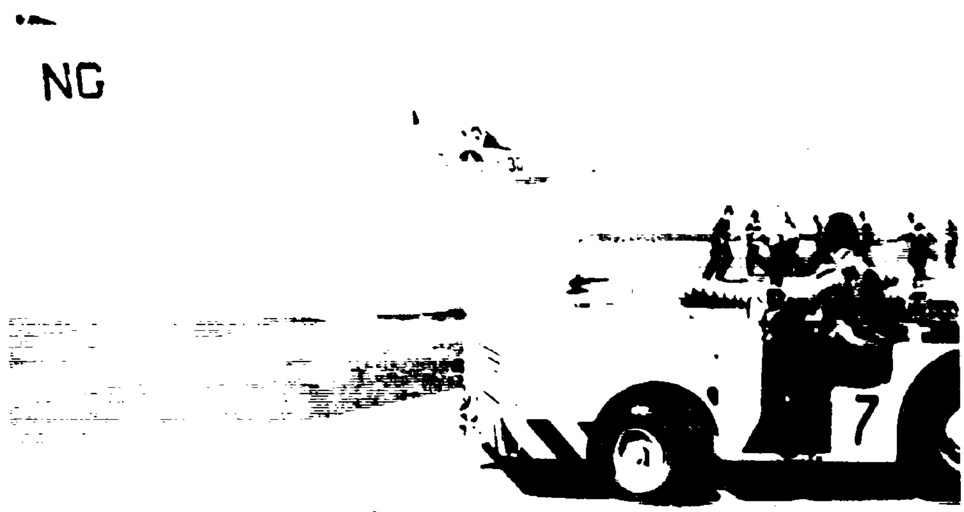
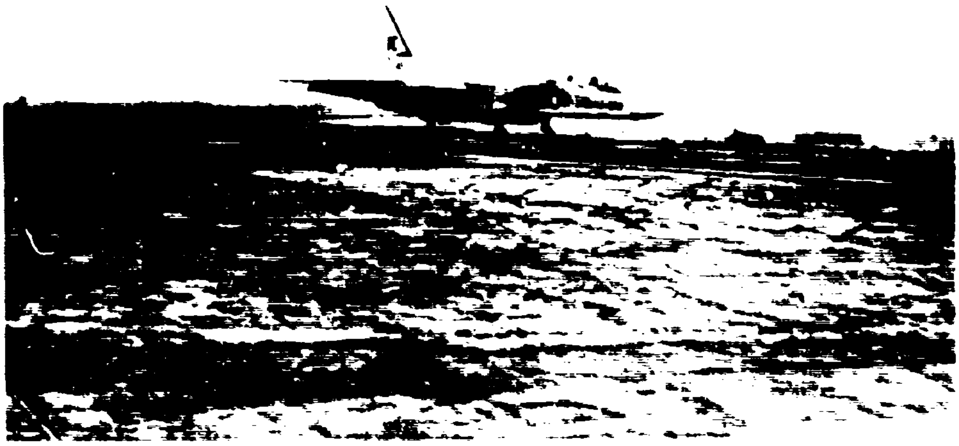


Figure 1. The A4 Skyhawk (A) on deck with "pushers" standing by, one hanging on wing to help stabilize it when taxiing, and (B) with crash and salvage crew standing by just after the plane has been released from the arresting-gear wire.

A.



B.

Figure 2. The RA5 Vigilante (A) landing (being trapped) and (B) launching (being catapulted in afterburner). Note the proximity of the crash and salvage crew and the hook runner on recovery, and of the Catapult Officer and at least one man in the catwalk on launch.

Figure 3. The A6 Intruder being catapulted from the angled deck. The Director is motioning for another aircraft to come into position on the port bow catapult which has just fired. Note the escaping steam.

These photographs are neither posed nor atypical and show only a few of the jobs performed by personnel working near operating jet aircraft on a flight deck. Other tasks include: (1) rolling under the aircraft on the catapult to check the bridle and hold-back connectors, (2) inspecting one or both afterburners to see that they are lit off, by looking in from near the blast deflectors, (3) running along beneath the wings of a taxiing, returning aircraft and replacing safeties on the unused returned ordnance, etc. It should be immediately obvious that personnel often are within actual contact with the aircraft and more often within five feet of it – and therefore exposed to dangerously high sound levels. (Such closeness presents the additional physical danger that a man may be sucked into, or blown off his feet by, the jet engines. Both of these accidents have happened, particularly the latter.)

A.

B.

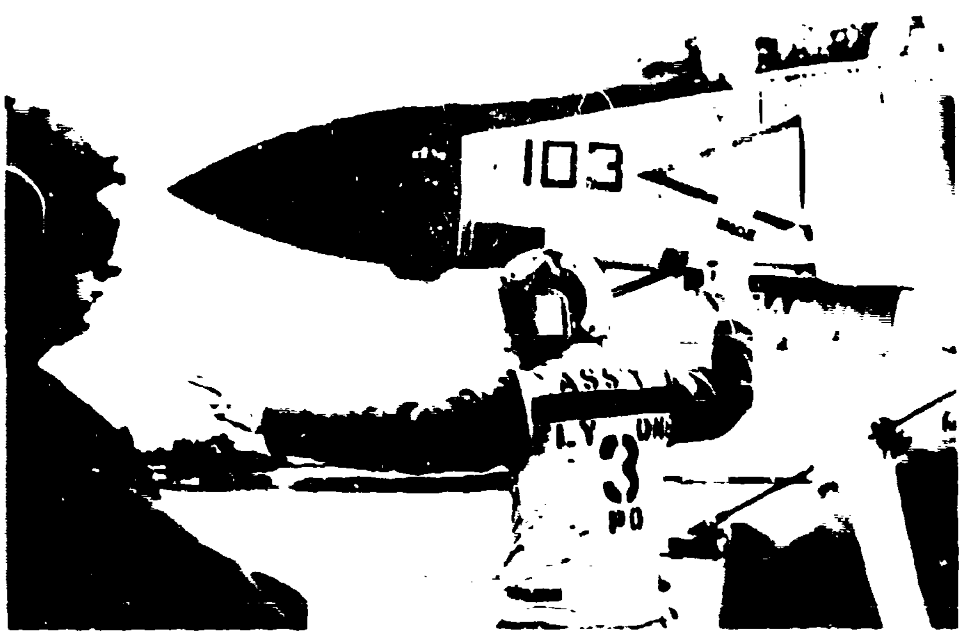


Figure 4. An F4 Phantom (A) being brought into position on the port bow catapult and (B) with bridle in place on the starboard bow catapult, being handed-off from the Fly One Director to the Catapult Officer.

A.

B.

Figure 5. Launching operations, showing proximity of personnel to plane prior to and during launch: (A) a "down" RA5 with "blue shirts" (pushers) helping to maneuver the aircraft off the catapult with engines running, and (B) A4's as seen from the island of the forward area of the flight deck.

Figure 6. Pilot trying to communicate to a Director, who is equipped with a flight-deck radio, beside an idling F4. Note that the pilot has removed his helmet and therefore has no hearing protection.

NOISE MEASUREMENTS AT NATC

NOISE LEVELS AROUND THE AIRCRAFT

Noise levels around the nose of four aircraft were measured at 30-degree intervals and at various distances. Results at a 50-foot distance are presented in figures 7-9. For the A4 and A6 (fig. 7) only the military power settings are shown. For the A5 (fig. 8) and F4 (fig. 9) both military power and afterburner noise levels are plotted. On all three figures the measured overall C-weighted levels and calculated A-weighting and speech-interference levels (average of the levels in the three octaves from 300 to 2400 Hz, called SIL 3/24) are also plotted.

Figure 10 is a replot of the data for the F4 at military power, detailing (by connecting the data points for each octave individually) the interaction among the frequency ranges and angle off the nose. It can be observed, for example, that the low-frequency energy (octave 1 from 32.5 to 75 Hz, and octave 2 from 75 to 150 Hz) increases toward the tail (pipe) of the aircraft.

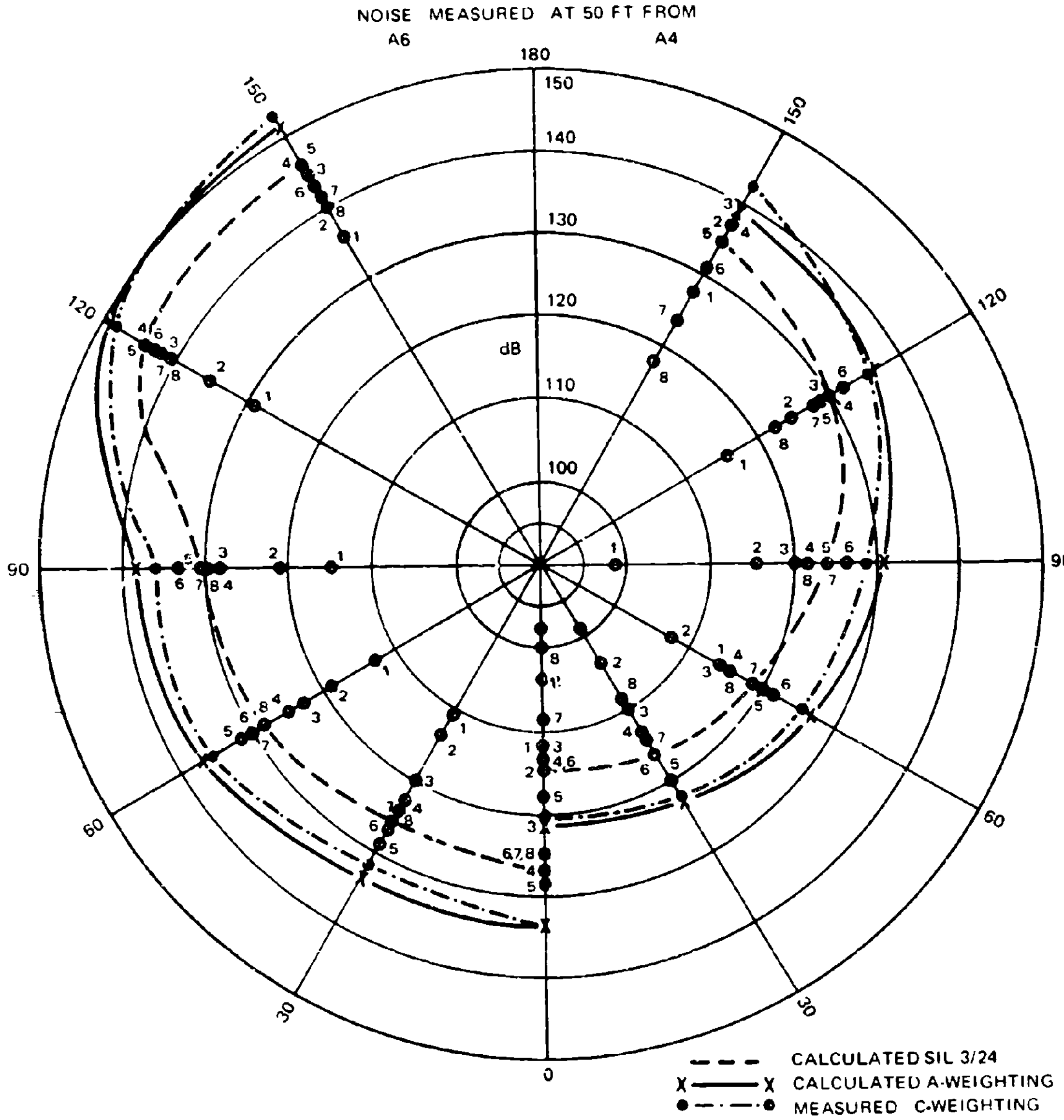


Figure 7. Noise levels of A4 Skyhawk and A6 Intruder running at military power, measured on a 50-foot radius at 30-degree intervals around the nose of the aircraft. C- and A-weighting and the 300-2400 Hz SIL are plotted. Numbers indicate octave band levels centered at (1) 53 Hz, (2) 106 Hz, (3) 212 Hz, (4) 425 Hz, (5) 850 Hz, (6) 1700 Hz, (7) 3400 Hz, and (8) 6800 Hz. (Data from refs. 4 and 5; reproduced with permission.)

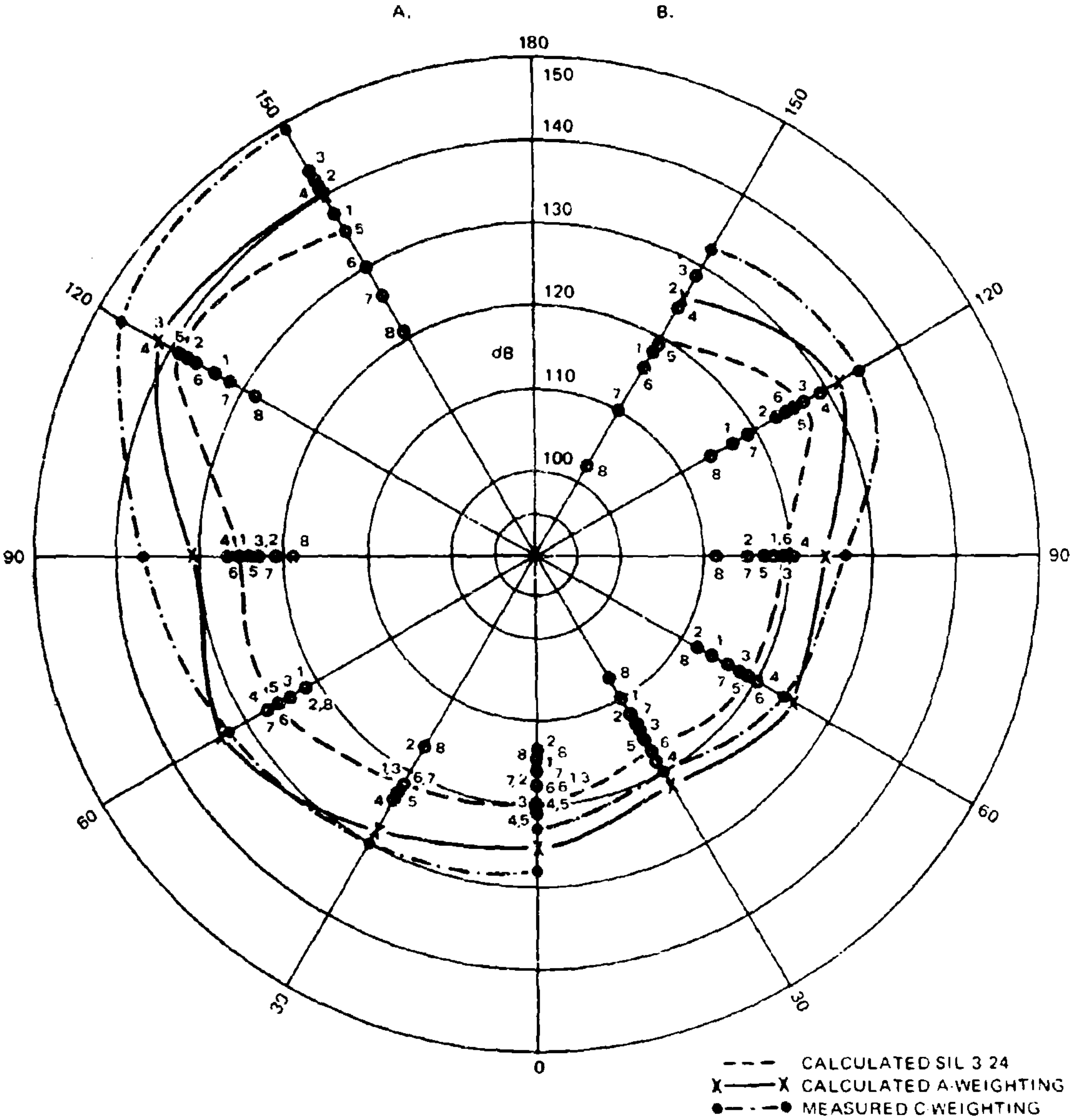


Figure 8. Noise levels of A5 running (A) in afterburner and (B) at military power, measured at 50-ft distance at various angles. C-weighting, A-weighting, and SIL 3/24 levels are also plotted. Numbers indicate octave band levels as defined in figure 7. (Data from ref. 2; reproduced with permission.)

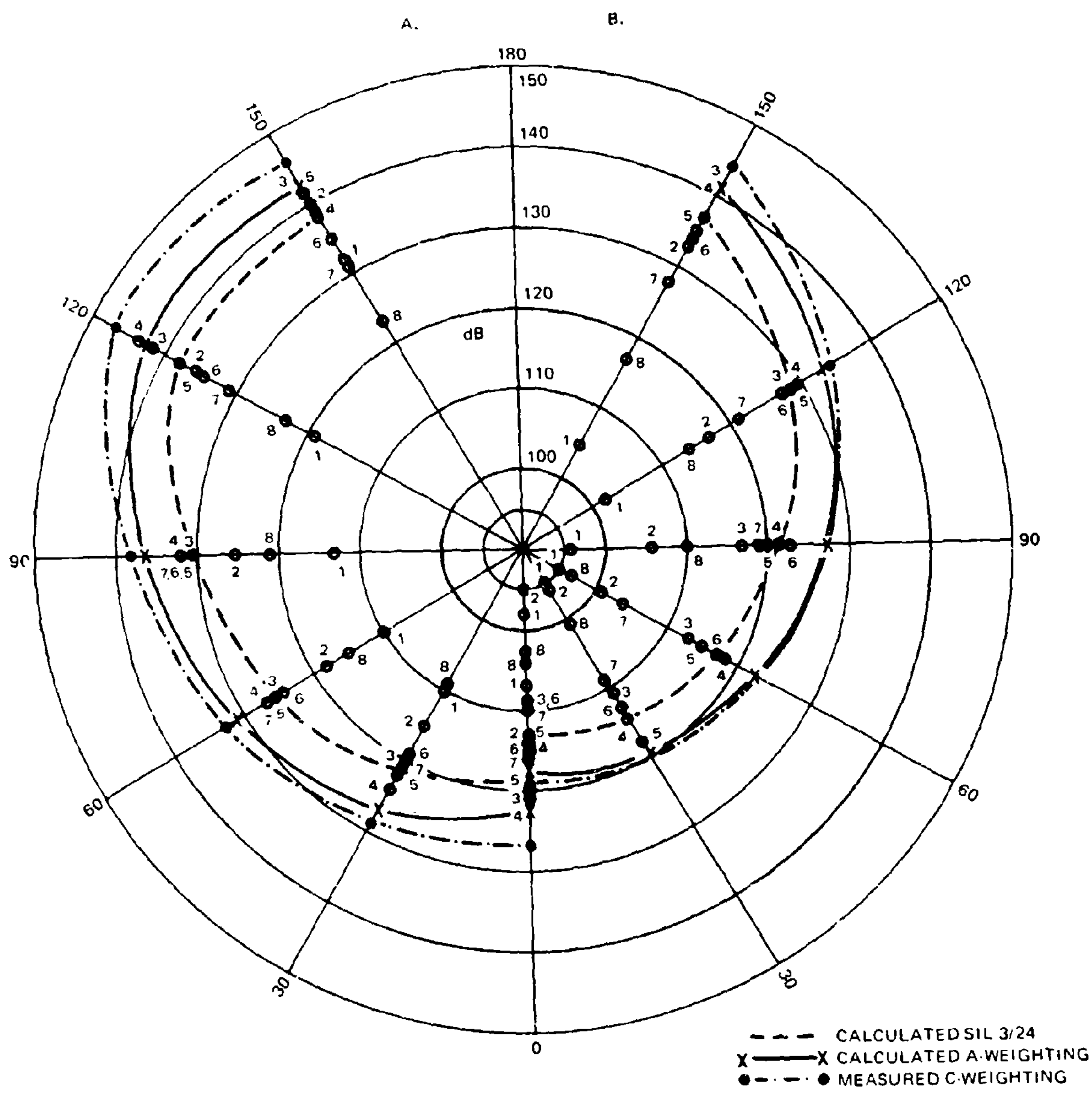


Figure 9. Noise levels of F4 running (A) in afterburner and (B) at military power, measured at 50-ft distance at various angles. C-weighting, A-weighting, and SIL 3/24 levels are also plotted. Numbers indicate octave band levels as defined in figure 7. (Data from ref. 3, reproduced with permission.)

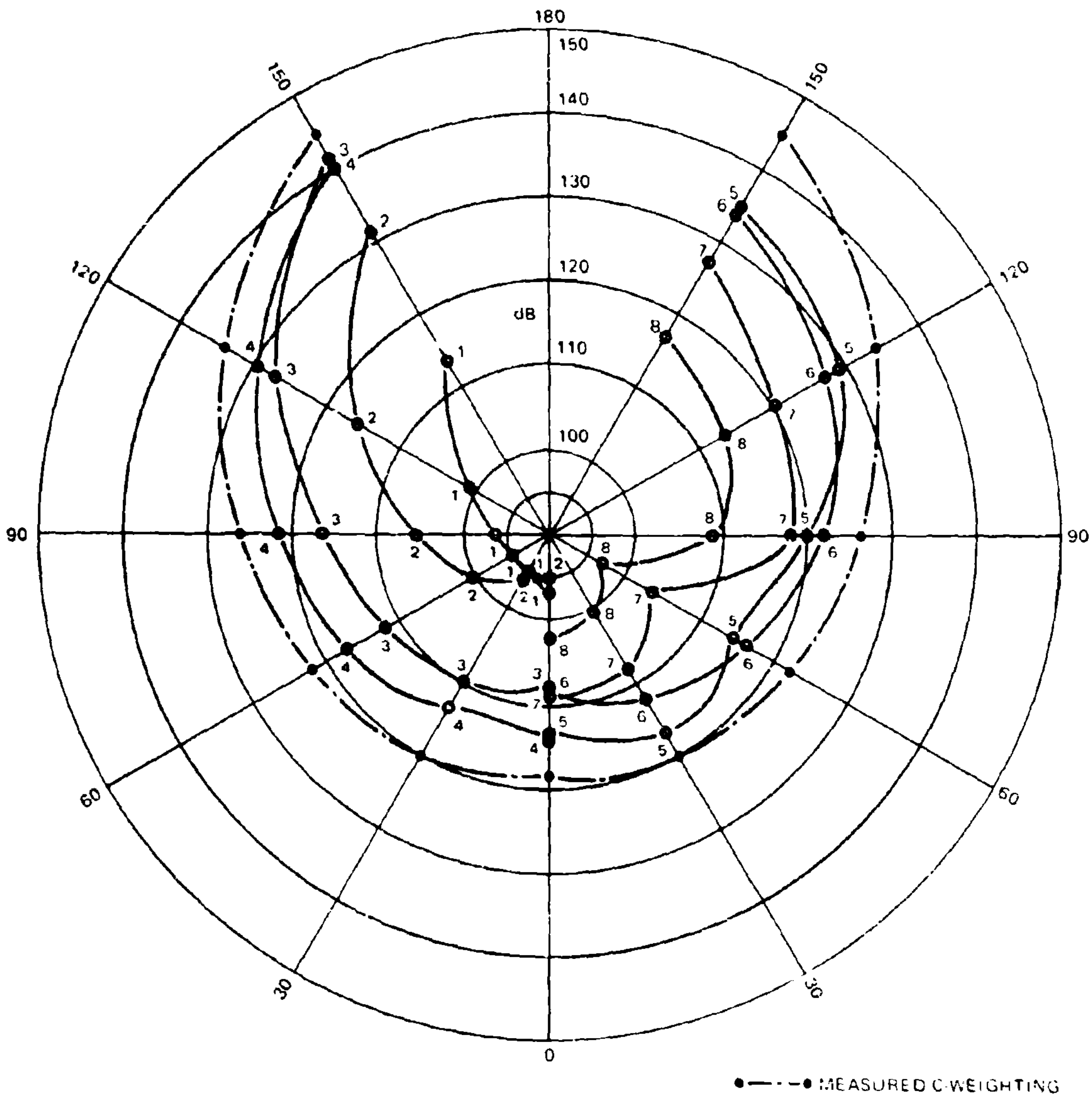


Figure 10. Noise levels of F4 at military power (two J79-GE-2 engines) measured at 50-ft distance at various angles, showing how each octave band level varies with angle. The octaves are labelled as in figure 7. (Data from ref. 3; reproduced with permission.)

From figure 7 it can be seen, for example, that the A6 shows an A-weighted level* about 10 dB greater than that of the A4. The noise level of the A6 increases from about 135 dBA in front (0°) of the aircraft increasing to 150 dBA, 30 and 60 degrees off the tail (120° and 150°). It is also evident that the A6 has relatively more of its noise energy in the higher octaves, 7 and 8 (above 1200 Hz), close to the tail. (Note differences of about 20 dB between the A4 and A6 levels for octaves 7 and 8 at 150°.)

When comparing figures 7 and 8, note that the C-weighted levels of the A5 at military power are very similar to the A4 levels except for a faster fall-off near the tail, while the A5 in afterburners is very similar to the A6 at military power. However, since the low-frequency energy is more predominant in the A5, especially close to the tail, the A-weighted levels drop off considerably.

From figure 9 it is evident that the F4 noise levels are quite similar to the A5 levels except that the A-weighted levels do not drop off so fast near the tail. Figure 10 shows how the lower octave levels increase dramatically when measured closer to the tail, while the upper ones increase at the same rate as the overall C-weighted level.

SPECTRAL-LEVEL DIFFERENCES WITH DISTANCE

Figures 11-16 show how the octave band levels and the measured C-weighted, calculated A-weighted, and 300-2400 Hz speech-interference levels change with distance from the aircraft on the 60-degree radial. If all measurement, power-source, and transmitting-medium (air) factors were ideal, a plot of these data would show sets of parallel lines 6 dB apart for each distance doubled. This is certainly not the case, although the trends are apparent. For example, there is on the average about a 24-dB difference between the closest (12.5 feet) and the furthest (200 feet) measurement points. (For the A5 at military power no measurements were taken at 200 feet and the difference between 12.5 and 100-- 12.5×2^3 -- is about 16 dB rather than the predicted 18 dB.) However, the difference between 100 and 200 feet exceeds 6 dB while the difference between 12.5 and 25 is usually (not always) less than 6 dB (for some octaves there is a reversal, i.e., more energy at 25 feet than at 12.5).

These discrepancies between observed and predicted (theoretical) measurements are certainly more than measurement error but are not unexpected. There are many reasons for expecting such variations from theory: (1) the sound source is not a point source nor is it fixed in location, (2) the medium is far from homogeneous since among other things the turbulence in the medium _is_ the sound source and the temperature

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*Sound-level meters conventionally have three frequency-weighting networks called A, B and C. An A-weighted measurement corresponds roughly to how the ear "hears" the noise in terms of loudness and/or interference with speech. For convenience the A-weighted level in decibels (dB) is sometimes called dBA. Whereas A-weighted levels progressively discount sound energies at frequencies below 1000 Hz, the C-weighted level gives equal weight to energy at all frequencies. C-weighted levels, often called dB, or dBC, bear very little relationship to how human beings "hear" sound and are used only to relate levels to physically oriented and/or older measurements. B-weighting is seldom used. See Young,[6] Webster and Klumpp,[7] Webster,[8] and Webster and Gales[9] for more details on how sound level meter weighting network levels and other more complex methods of measuring sound (noise) correspond to subjective attributes of loudness, annoyance, and speech interference.

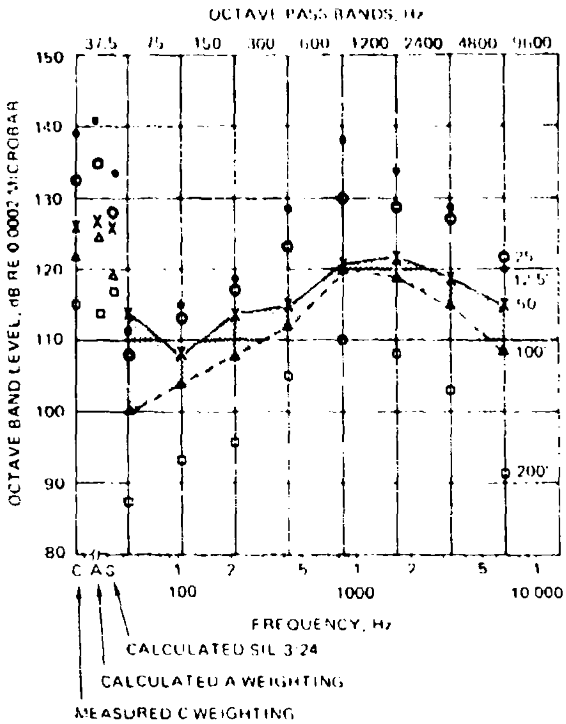

Figure 11. Octave bands (octaves 1 through 8 as labeled in fig. 7), plus C-, A-, and SIL-weighted noise levels for the A4 running at military power, measured 60 degrees off the nose, at various distances. (Data from ref. 5; reproduced with permission.)

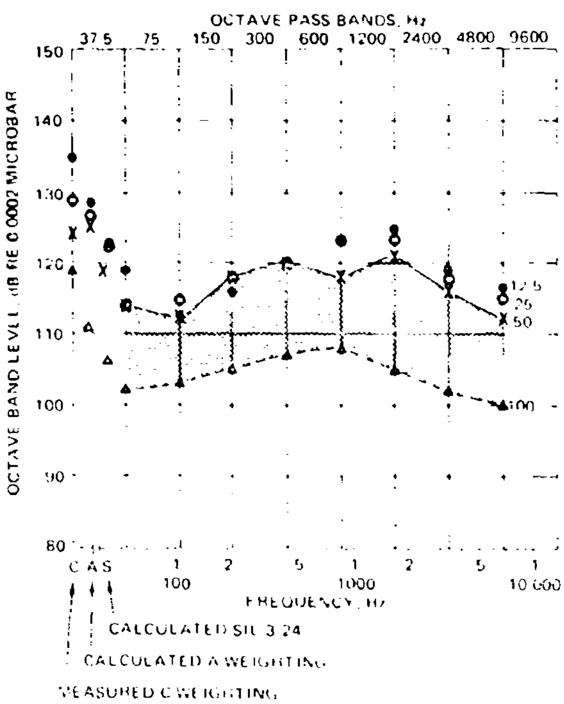

Figure 12. Octave bands (octaves 1 through 8 as labeled in fig. 7), plus C-, A-, and SIL-weighted noise levels for the A5 running at military power, measured 60 degrees off the nose at various distances. (Data from ref. 2; reproduced with permission.)

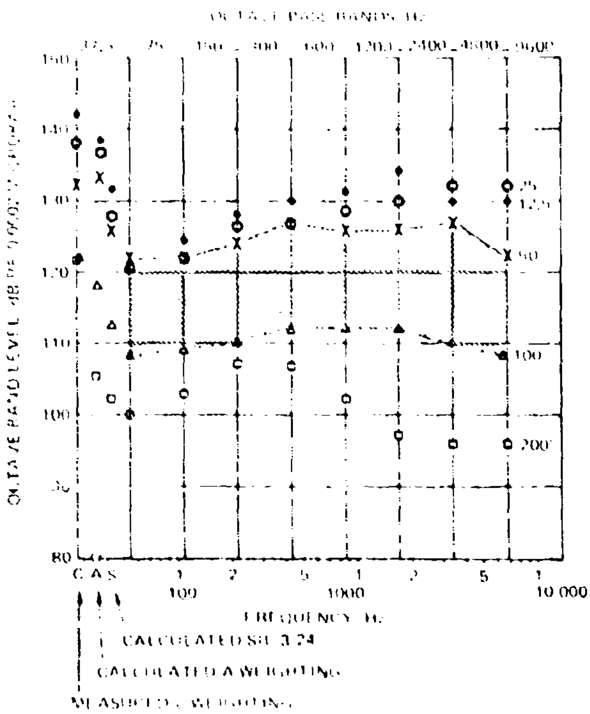

Figure 13. Octave bands (octaves 1 through 8 as labeled in fig. 7), plus C-, A-, and SIL-weighted noise levels for the A5 running in afterburner, measured 60 degrees off the nose at various distances. (Data from ref. 2; reproduced with permission.)

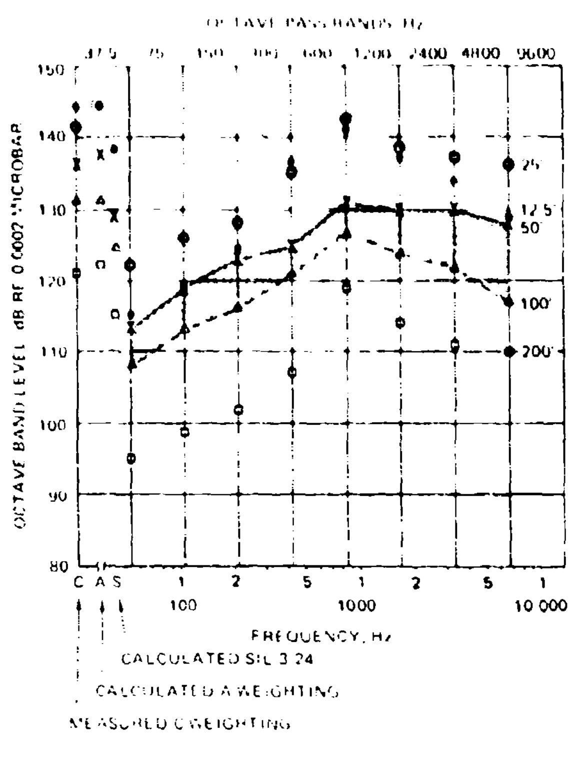

Figure 14. Octave bands (octaves 1 through 8 as labeled in fig. 7), plus C-, A-, and SIL-weighted noise levels for the A6 running at military power (two J52-P-6 turbojet engines), measured 60 degrees off the nose at various distances. (Data from ref. 4; reproduced with permission.)

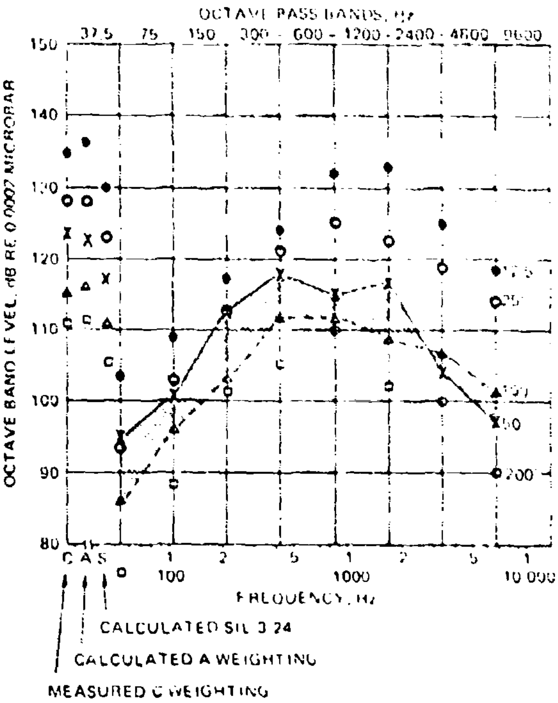

Figure 15. Octave bands (octaves 1 through 8 as labeled in fig. 7), plus C-, A-, and SIL-weighted noise levels for F4 running at military power, measured 60 degrees off the nose at various distances. (Data from ref. 3, reproduced with permission.)

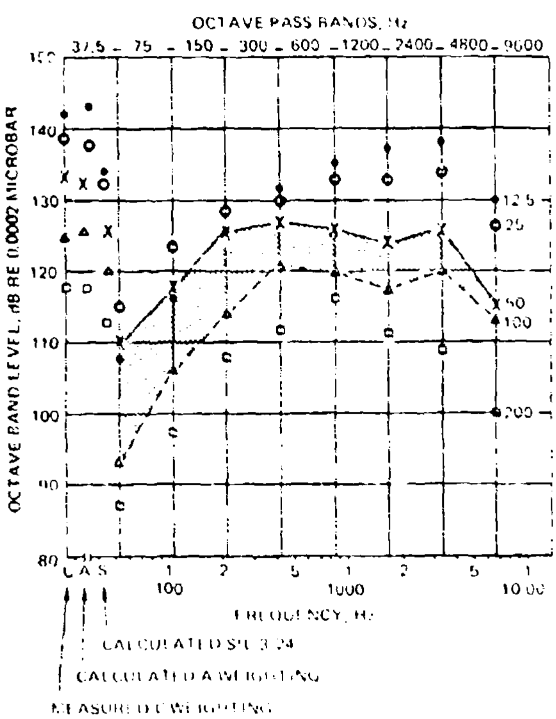

Figure 16. Octave bands (octaves 1 through 8 as labeled in fig. 7), plus C-, A-, and SIL-weighted noise levels for F4 running in afterburner, measured 60 degrees off the nose at various distances. (Data from ref. 3 reproduced with permission.)

gradients are large, and (3) the power settings are not necessarily completely repeatable. Time is required to make the measurements and the engine would overheat if all measurements were made at one setting, etc., etc. The point is not so much that the measurements differ from perfectly predictable measurements but that variations as great as those observed here do actually exist.

If one used recordings of these noises to simulate typical sound fields in a laboratory situation, homogeneous sound fields would be atypical. Similarly, in using these levels to interpret their effects on speech or hearing, an error of about ±3 dB should be acceptable.

It should be noted in comparing the noise spectra of the various naval aircraft that the A4 and F4 have spectral peaks around 1000-2000 Hz (A4) and 500, 1000, 2000 Hz (F4), while the A5 spectrum is relatively flat and the A6 rises to about 1000 Hz and stays relatively high thereafter. In afterburner the F4 spectrum has a broad peak between 200 and 3500 Hz.

NOISE MEASUREMENTS ABOARD USS KITTY HAWK

COMPARISON WITH NATC DATA

The noise data discussed so far have all been taken from measurements made at the Naval Air Test Center (NATC) in Patuxent River.[2-5] Comparisons will now be made between the NATC data and the noise levels of A4 and F4 aircraft making carrier-qualification launches, recoveries, and touch-and-go passes on USS KITTY HAWK.[1] In the KITTY HAWK data, emphasis was on finding variations of level at various communicating positions on the flight deck and, more particularly, the time variation at the bow-catapult-amidships-control position on the flight deck.

From recorded steady-state portions of these measurements, spectra (octave band levels) were plotted in the laboratory for three conditions: (1) an A4 and (2) an F4 during military power ("two-finger") run-ups on the bow catapults and (3) the ambient noise from A4's and/or F4's taxiing and idling in the near vicinity of the catapults. These results are shown in figures 17 and 18, with a comparison of corresponding measurements made ashore by NATC.

Figure 17 shows octave-band, C-weighted, A-weighted, and PSIL (speech-interference levels for octaves centered at 500, 1000, and 2000 Hz) levels for the A4 in a bow-catapult position during a two-finger run-up on KITTY HAWK. Also shown are the noise spectra for the ambient (no run-up) condition, during which the aircraft are taxiing but not in military power. Figure 18 is identical to figure 17 except that the F4 is the noise source. In both cases the data were chosen for comparison with those reported by NATC[2-5] because the 30-degree angle and 50-foot distances closely correspond to conditions of the NATC measurements.

It is immediately apparent in comparing the onboard noise levels with those measured ashore that there is a strong concentration of low-frequency energy measured onboard. It is possible that in the case of the ambient noise, the high level may include the noise generated by the presence of at least 30 knots of wind across the microphone of the sound-level meter. This effect is well known[10] but has not been documented accurately enough to permit suitable corrections. In any case, the wind which blows across the microphone of the sound-level meter is generating similar noise around a person's ears and around the microphones, earmuffs,

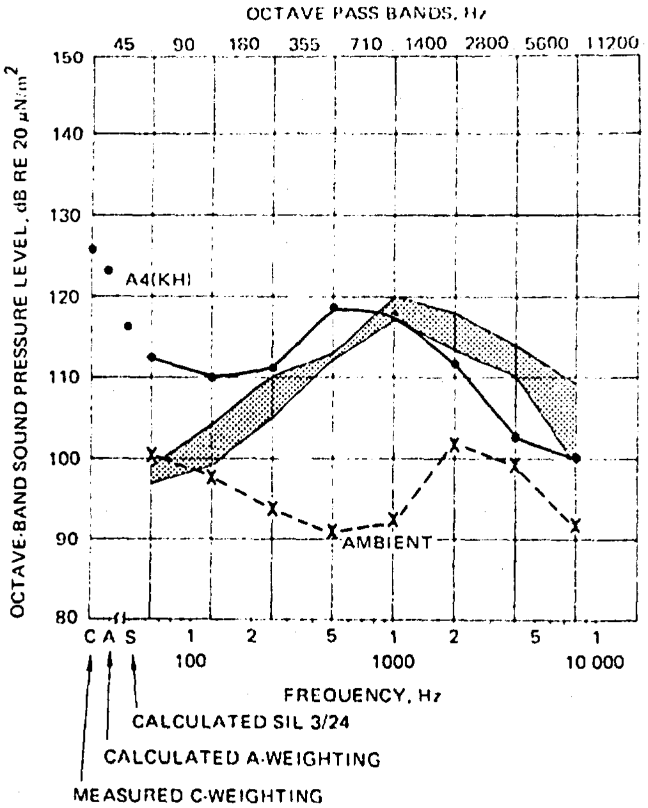

Figure 17. Octave band plus C-, A-, and SIL-weighted noise levels for the A4 running at military power, measured on a bow catapult of USS KITTY HAWK (•). Also shown is ambient noise (x) on flight deck of KITTY HAWK with F4's and/or A4's idling or taxiing (Data from ref. 1.) Shaded area encompasses noise levels measured 30 degrees off the nose of an A4 at 50 and 100 feet, as reported by ref. 5.

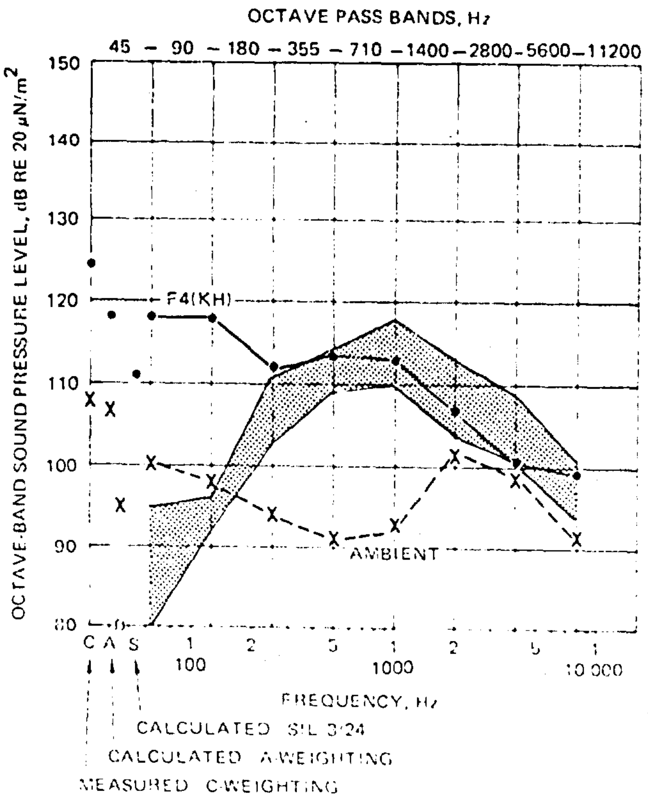

Figure 18. Octave band plus C-, A-, and SIL-weighted noise levels for F4 running at military power, measured on a bow catapult of USS KITTY HAWK (•). Also shown is ambient noise (x) on flight deck of KITTY HAWK with F4's and/or A4's idling or taxiing. (Data from ref. 1.) Shaded area encompasses noise levels measured 30 degrees off the nose of an F4 at 50 and 100 feet, as reported in ref. 3.

and headsets of communication and/or ear-protective devices.[11] The amount of masking introduced by a 30-knot wind is about 52 dB in the speech range and can be reduced by a little more than 10 dB by using an ear wind-screen.[11] In the KITTY HAWK measurements made by the NELC team, the exact amount of "masking" introduced by the wind across the General Radio ceramic microphone (which was used in an appropriate wind-screen) is not known.

The contribution of wind to ambient noise suggests two problems requiring further investigation: (1) what wind corrections are required in the physically measured data and (2) how much noise is generated by the wind on acoustic transducers and hearing protectors used as integral parts of flight-deck communication equipments.

The presence of excessive low-frequency energy in the A4 and F4 spectra cannot be explained by wind across the measuring microphone. The wind does not increase during a two-finger run-up, yet the low-frequency energy increases 12 dB (fig. 17) or 18 dB (fig. 18). The explanation that first comes to mind points to the presence of the blast deflector aboard and the absence of it ashore. Pure speculation is (1) that low-frequency energy is generated by the jet blast impinging on the deflector or (2) that the noise-generating vortices are deflected up off the deck or to the sides of the deflector. The hypothesis is that the noise is generated above or at the sides of the deflector instead of behind the tailpipe, thereby actually bringing the source closer to the measuring microphone (and men) ahead of the aircraft. This speculation should be followed up with tests and measurements to verify or refute it.

DETRIMENTAL EFFECTS OF FLIGHT-DECK NOISE

DEAFNESS RISK TO PERSONNEL

Although hearing damage is a medical problem and not the primary concern of engineers designing communications equipment, it was nevertheless deemed necessary and desirable in this report to reevaluate deafness risk in terms of the measured noise levels of current aircraft operating with today's schedules. This is considered necessary if for no other reason than to caution communication engineers that their equipment should not be the last straw that makes the total noise environment potentially deafening to the men in it.

The problem of noise-induced hearing loss was recognized as soon as jet aircraft were put aboard carriers.[12] Programs of noise measurement and hearing monitoring were carried out with the general conclusions that with care (primarily wearing earmuffs and giving annual audiometric tests), no danger of noise-induced, permanent hearing loss existed. Subsequently, a group of academic, military, and industrial audiologists working under the auspices of CHABA (Committee on Hearing and Bio-Acoustics) developed predictive formulas for evaluating exposure to noise as a correlative of hearing impairment or deafness.[13] An industrial safety engineer, J. H. Botsford,[14] refined these formulas, and in 1970 an intersociety committee[15] brought the predictive methods up to date. Table 1 (from ref. 15) is a simplified summary of their findings of acceptable exposures to noise as a function of the number of times such exposures occur daily.

The noise levels to which flight-deck personnel are exposed varies according to what flight operations (ops) are scheduled and where the man

TABLE 1. ACCEPTABLE EXPOSURES TO NOISE IN dBA AS A FUNCTION OF THE NUMBER OF OCCURRENCES PER DAY.*

Daily Duration		Number of times the noise occurs per day						
Hours	Min	1	3	7	15	35	75	160 up
8		90	90	90	90	90	90	90
6		91	93	96	98	97	95	94
4		92	95	99	102	104	102	100
2		95	99	102	106	109	114	
1		98	103	107	110	115		
	30	101	106	110	115			
	15	105	110	115				
	8	109	115					
	4	113						

To use the table, select the column headed by the number of times the noise occurs per day, read down to the average sound level of the noise and locate directly to the left in the first column the total duration of noise permitted for any 24 hour period. It is permissible to interpolate if necessary. Noise levels are in dBA.

*From ref. 15, p. 23.

is on the deck. Concerning flight-ops, two typical cases will be cited: carrier qualifications (CARQUALS) and cyclic air-ops off Southeast Asia. In CARQUALS, pilots continually launch and land until they are "qualified." Figure 19 shows the A-weighted sound-pressure levels measured over a 45-minute period of continuous launchings of A4 and F4 aircraft. The ambient noise is produced by the same aircraft taxiing onto the catapults. The recordings were taken just aft of the instrument panel which is located between and forward of the bow catapults. Many men gather in their assigned locations, waiting to help in case of emergencies. Many personnel are in even noisier locations as shown in figures 1-6. The sequence shown in figure 19 could run in roughly a 45-minute "on" cycle (as shown) with an "off" cycle of 15 minutes to a few hours, for 18 hours a day, but only for a 4- to 8-day cycle.

Another representative case is that of the cyclic air-ops schedules carried on at Yankee (Dixie) station in WESTPAC. Figure 20 is an estimate of the time sequence of noise levels during a 12-hour cyclic-air-ops schedule. It is based on:

1. Aircraft noise levels shown in figures 7 through 18.

2. Changing noise levels during launching sequences similar to figure 19.

3. Resting noise levels (non-air ops) typical of interior spaces.[16, 17]

Further assumptions applied to the data in figures 7-19 that lead to figure 20 are:

4. The A3 and A6 aircraft operating on WESTPAC CVA's are about 5 dB noisier than the F4 and A4.

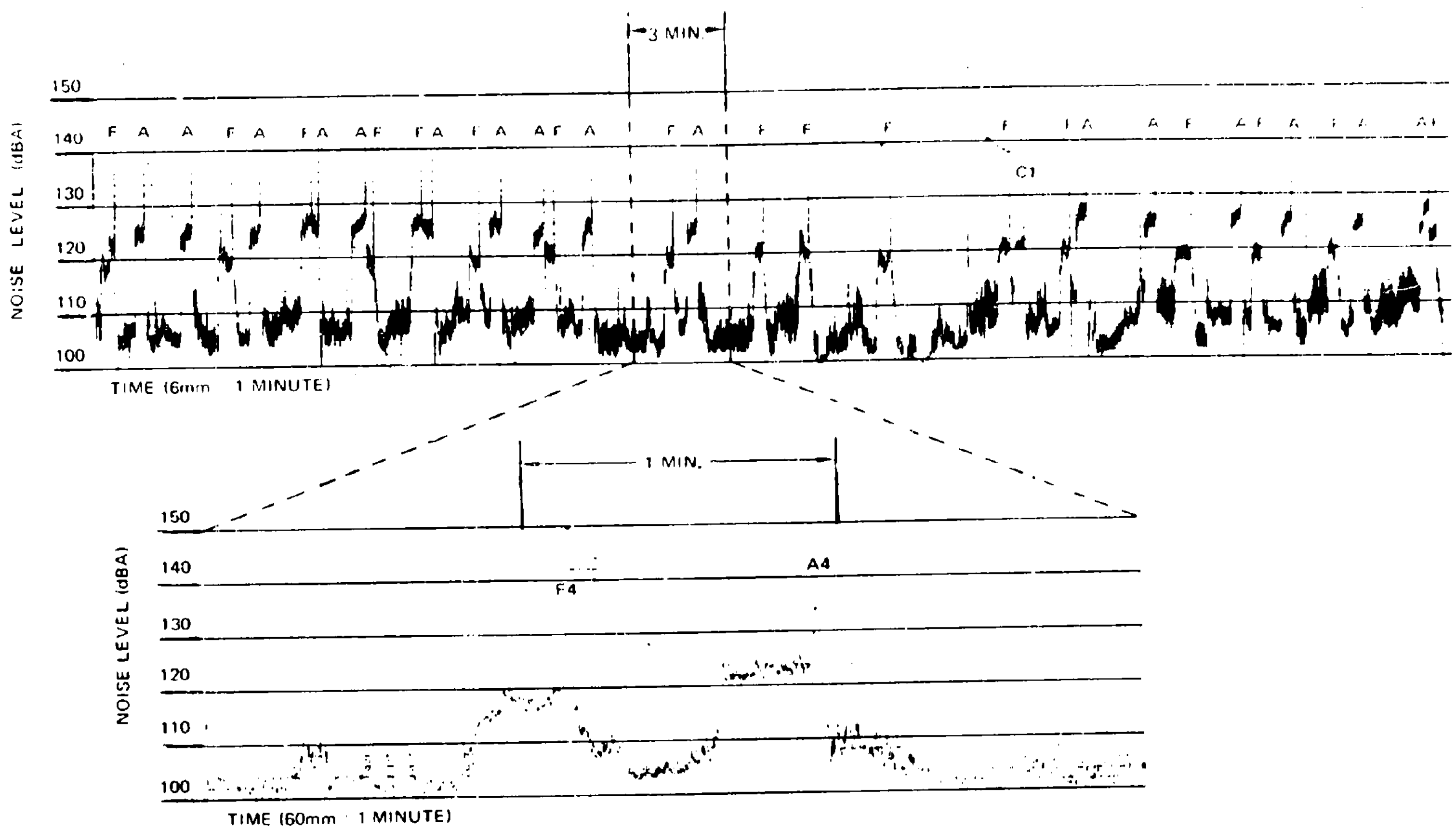

Figure 19. A-weighted sound-pressure levels measured over a 45-minute period during carrier qualification operations aboard USS KITTY HAWK (from ref. 11). Measured at bow-catapult instrument-panel position during repeated launches of F4 (marked F) and A4 (marked A) aircraft.

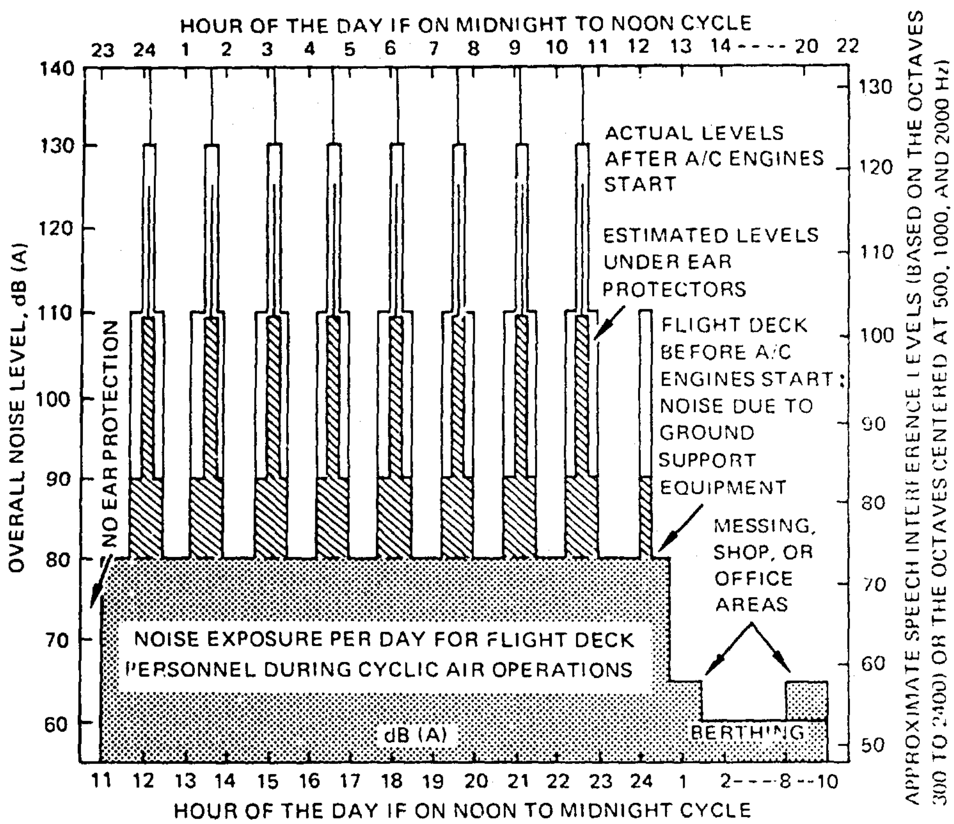

Figure 20. Estimated daily noise exposures for men working on flight deck during 12-hr cycle air operations. It is assumed that (1) the men will not wear hearing protection until the aircraft engines are started that is, when ground-support equipment is producing noise levels averaging around 80 dBA and (2) they will wear earmuffs or plugs once the engines have started.

5. The noise levels at the Bow Catapult Officer's location are typical of the noise levels from this position all the way aft on the flight deck (and the area forward of his position is quieter and not covered by figure 20). It is apparent (figs. 1-6) that many personnel are at noisier locations (closer to the tailpipe and/or noise-generating vortex). Many are at less noisy positions (distances beyond 100 feet).

6. The 30-second-on, 30-to-60-second-off duty cycle shown in figure 19 as lasting 45 minutes for CARQUALS lasts for roughly 15 minutes during a cyclic air-ops launch. The 15 minutes prior to the launch and the 15 minutes of recovery after the launch are at the ambient level shown as the base level in figures 17, 18, and 19.

7. The 3-second roll-by peaks (rising to 140 dBA as shown in the detailed time trace of figure 19) that accompany each launch occur roughly 30 times in the 15-minute launch cycle (or for a total of 1.5 minutes).

8. The passive or flight-deck radio "Mickey Mouse" earmuffs provide an average of 20-dB attenuation* when worn.

9. The muffs are worn only when the jet aircraft engines have started that is, when the levels in figure 20 exceed 80 dBA.

10. The exposure to levels between 65 and 80 dBA are intermittent because the ground-support equipment moves around over the deck exposing different people for different amounts of time (estimated 50-percent duty cycle).

11. The exposure levels between 90 and 110 dBA (peaks to 125) with the men wearing earmuffs are intermittent with a duty cycle of 50 percent because on the average during cyclic air-ops two aircraft per minute are launched for roughly 15 minutes.

Assuming these eleven conditions, the shaded areas in figure 20 really represent the noise-exposure contour because (1) at levels less than 80 dBA (before aircraft engines are started) no one wears earmuffs and (2) at levels above 80 dBA (once the engines have started) everyone on the flight deck wears muffs. Daily exposures would, therefore, be roughly (1) between 110 and 125 dBA (call it 115 dBA), 1.5 minutes × 8 cycles or 12 minutes/12 hours; (2) at 110 dBA, 7.5 minutes × 8 cycles or 60 minutes /12 hours; (3) at 90 dBA, 30 minutes × 8 cycles or 240 minutes /12 hours. Interpreting these exposures in terms of the 1970 intersociety committee's concensus report, table 1 shows that for 8 cycles per day (use the 7 column):

1. 115 dBA could be tolerated for 15 minutes instead of the 12-minute exposure calculated above,

2. 110 dBA could be tolerated for 30 minutes but the calculated exposure is 60 minutes, and

3. 90 dBA could be tolerated for 8 hours and its exposure is calculated at 4 hours.

The implication is that unless the launch-recovery cycles are reduced by one-half, or unless the muffs attenuate 23 dB rather than 20 dB, a deafness hazard exists. If nothing more, the calculations show that the exposures are at or near the damage-risk area. This should indicate the need for a continual search for better earmuffs, and measurement of noise levels and hearing losses on a continuing basis.

In addition to shortening the air-ops cycle and providing the best possible ear protection, two steps should be taken immediately to minimize deafness risk: (1) the liquid-filled sealing pads for the "Mickey Mouse" muffs and/or radios (SRC-22(V)) should be replaced whenever the seal is broken and at least once a year, and (2) as part of the routine announcement over the flight-deck announcing system (5 MC) prior to starting engines, a statement should be added to the effect, ". . . . all people without hearing protectors leave the flight deck, all others don your earmuffs – stand by to start engines."

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*Based on the fact that the sealing rings on muffs found on CVA's are in notoriously bad condition – hard, brittle, torn, missing, repaired with masking tape, etc. – and that even with new devices, average attenuation on most muffs is on the order of 20 dB. See ref. 18.

DEGRADATION OF SPEECH COMMUNICATIONS

A primary concern in designing communications equipment to function in the noise levels found aboard CVA's is the speech-interference levels (SIL)* of such noises. Figure 21 plots the calculated SIL of typical aircraft noises measured on a CVA flight deck. Although a comprehensive study at NELC[7] showed that the SIL and/or PSIL provides the best means for predicting the speech-interfering aspects of noise, an A-weighted reading of the sound-level meter was shown to be adequate. It offers the advantage of easy measurement and interpretation and is probably the best single measure of noise, as it involves human perception. Therefore, the right-hand ordinate of figure 21 is a scale of comparative A-levels for the same measurements.

To aid in interpreting the SIL and A-weighted aircraft noises in terms of limitations on speech communications, some pertinent tables and figures developed at NELC and the Western Electro-Acoustic Laboratories in Los Angeles will be presented here.

Consider first figure 22 which shows the general ranges of noise levels in which face-to-face, SPP, and amplified speech communications are possible. This figure was adapted from an earlier study (ref. 20) by relabeling (recalibrating) the abscissa. The original abscissa was based on a particular jet-aircraft noise that had distinct tonal components around 3000 Hz and that gave high octave-band noise-level readings in the octaves centered at 2000 and 4000 Hz (see fig. 16 in ref. 21). It is evident from the results of reference 21 that these high-level, high-frequency tonal components added to measured C-weighted, A-weighted, and speech-interference levels but did not cause a proportional amount of speech masking. The ambient jet noise measured on KITTY HAWK did not contain discernible tonal components because, among other things, it consisted of melded levels of more than one aircraft. However, unlike the jet noise of reference 21, the ambient level on KITTY HAWK contained neither discernible tonal components nor high amounts of dispersed energy at 2000 (and 4000) Hz. Consequently, its A-weighted level is relatively lower than the jet noise of reference 21. In lieu of running new intelligibility tests, it is assumed that the A-weighted level would be 15 dB (instead of 21 dB as for the old jet noise) above the equivalent PSIL for the reference standard noise of -6 dB per octave used in the original figure.[20]

Also added to figure 22 are the results of some intelligibility tests of the newer dynamic noise-canceling microphones (M87 and M101),[22] conducted by the Aerospace Medical Research Laboratories. In plotting the AMRL and NELC data it was assumed that the rhyme words used by NELC in the

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*At present there is, and will be, some confusion between acronyms and definitions of speech-interference levels. The original and accepted use of "speech interference level" (SIL) was based on average dB levels of noise in the octaves 600-1200, 1200-2400, and 2400-4800 cps (Hz). See ref. 19. In the meantime, international and U.S. standardization groups have accepted octaves based on center frequencies of 31, 63, 125, 250, 500, 1000, 2000, . . . Hz as preferred octaves of noise measurement. A new American National Standards Institute (ANSI) definition of speech-interference level based on the octaves centered at 500, 1000, and 2000 Hz is in the process of adoption. The new SIL is often referred to as PSIL-Preferred [octaves] SIL. In this report the measures from NATC were made in the 300-600, 600-1200, . . . octaves and those on KITTY HAWK, in the 250, 500, . . . octaves; consequently the speech-interference levels of the NATC data are SIL, and the newer ones are PSIL. In general, PSIL's are 3 dB greater than SIL's (see Appendix).

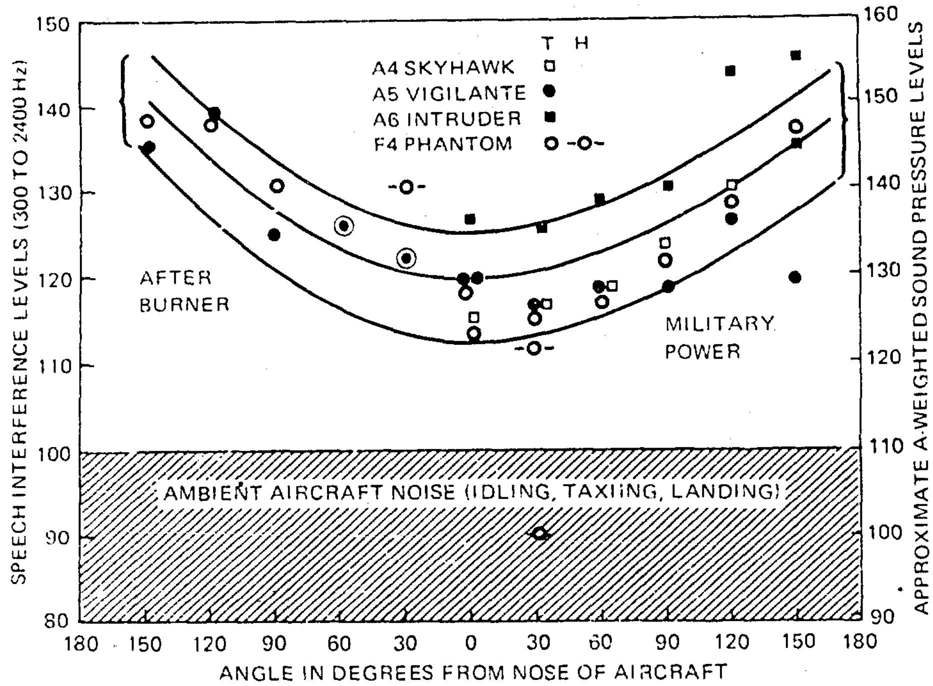

Figure 21. Speech-interference levels (SIL) in the 300-2400 Hz band at 50 feet and various angles from typical naval jet aircraft operating at military power (at right) and in afterburner (at left).

tests were 10 percent more intelligible[23] in any given fixed speech-to-noise differential than the phonetically balanced (PB) words used by AMRL. The relative speech-interfering properties of the two different samples of jet noise were interpreted in terms of the data in reference 7. The fact that the AMRL data lie between the no-noise shield (left) and noise shield (right) boundaries of the NEL(C) data confirm that the M87 and M101 microphones are as good as but not spectacularly better than the M33 microphone used for the NEL(C) tests.

In interpreting figure 22 note that within any speech listening mode, word intelligibility decreases as noise levels increase. This poses the question of what word score is "adequate" as a system criterion. In general, it has been found that an articulation index (AI) of 0.4 will yield sentence scores in excess of 95 percent, which is generally adequate for military communication systems. An AI of 0.4 corresponds to a PB word score of 63 percent which, according to Montague,[23] is the equivalent of a rhyme-word score of 75 percent. This is the "criterion" score that will be used in the remainder of this report when referring to adequate or satisfactory communications over military systems. However, when referring to face-to-face communications, an AI of 0.5 (corresponding to a rhyme-word score of 85 percent)[23] will be the criterion,[24] to provide compatibility within the extensive work done by L. L. Beranek on acceptable noise levels for workers in office spaces.[25]

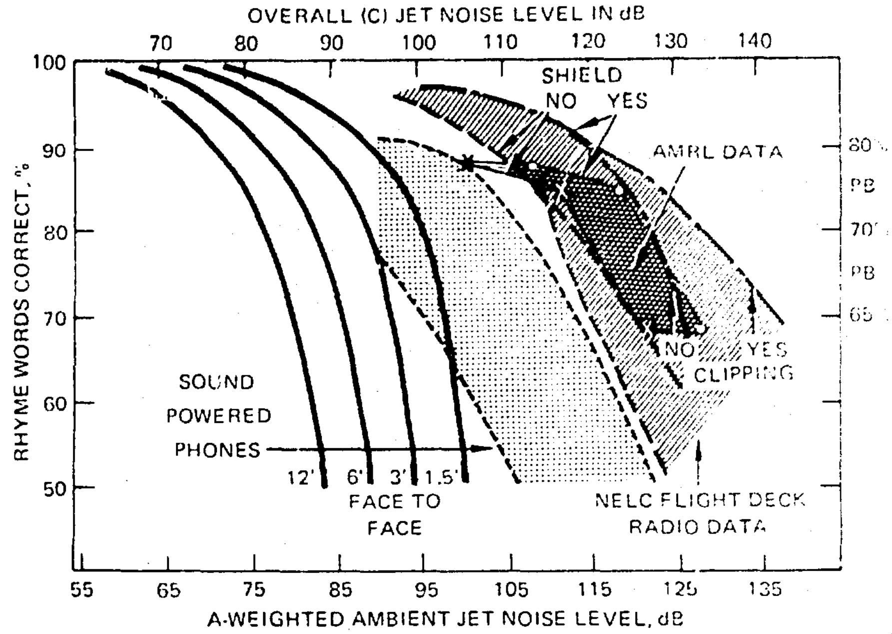

Figure 22. Rhyme-word intelligibility scores for face-to-face, sound-powered phone, and amplified speech conditions as a function of ambient jet-aircraft (idling) noise. Adapted from ref. 20.

Figure 23 breaks down the "face-to-face" portion of figure 22 in more detail, and in particular takes into account the very relevant parameter of the speaker's voice level. The speaker who generated the data on face-to-face intelligibility in figure 22 spoke at a level commensurate with his task namely, to get listeners sitting in front of him to understand his words. He raised his voice at least as much as the "expected voice level" line in figure 23 and probably approached the "communicating voice" level.

Both figures 22 and 23 can be interpreted to show that when the jet-aircraft engines have started and noise levels average around 110 dBA, face-to-face communications are severely limited. In fact, when the talker is shouting, (fig. 6), often with cupped hands between his mouth and the listener's ear, only rudimentary and/or emergency messages are even attempted. During cyclic air operations, levels of 110 dBA, or higher, occur roughly half of the time.

Table 2, adapted from reference 20, summarizes the limitations on voice communications imposed by six stratifications of noise. This is a gross classification; more details are shown in figures 22 through 25. Note, however, that the flight-deck announcing system, the 5 MC, cannot be expected to communicate to all personnel once the jet engines have started and noise levels average out at 110 dBA.

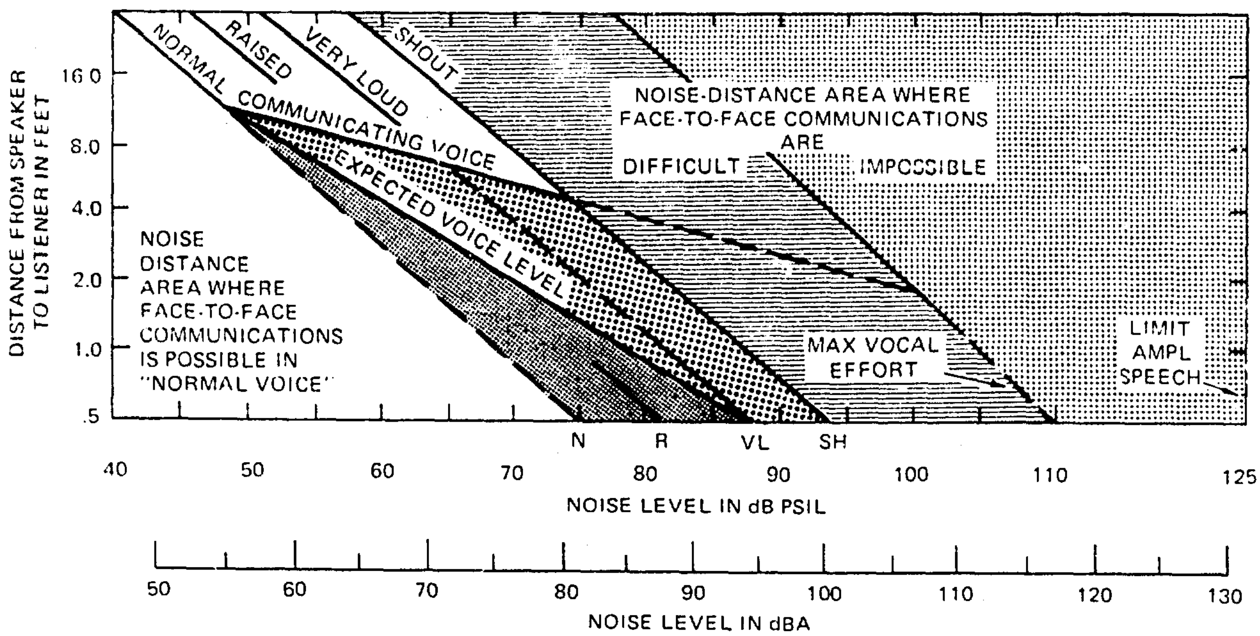

Figure 23. Distance between communicators for satisfactory face-to-face speaking as a function of noise level measured in PSIL units. Parameters are vocal effort - normal, raised, etc., as shown.

TABLE 2. SPEECH COMMUNICATION CAPABILITIES IN VARIOUS LEVELS OF AMBIENT ACOUSTIC NOISE.

Communication Facility	Noise Level in dB, Measured on A-Weighting of a Sound-Level Meter: Category 1, <50	Category 2, 50-70	Category 3, 70-90	Category 4, 90-110	Category 5, 110-130	Category 6, 130
Face-to-face	Speakers may converse in normal voice at distances of 20 feet	Speakers may be separated by from 3 to 20 feet if raised voice level is used	Raised or very loud vocal effort required for communication from 1 to 3 feet	At maximum vocal effort, communication distance is 1 foot	Very difficult to impossible even at 0.5-inch separation	Impossible
Conventional IC squawk box	Good	Satisfactory to difficult	Unsatisfactory	Impossible	Impossible	Impossible
Conventional IC telephone	Good	Satisfactory to slightly difficult	Difficult to unsatisfactory	Use press-to-talk switch; acoustic booth needed	Use special transducers	Impossible
Sound-powered phones	Good	Satisfactory to difficult	Difficult to unsatisfactory	Difficult to unsatisfactory	Unsatisfactory	Impossible
		with old-style equipment		with improved (noise-proofed) equipment		
Flight deck radio SRC-22V	Good	Satisfactory but cumbersome	Satisfactory but cumbersome	Satisfactory	Satisfactory	Inadequate (lacks mike noise shield)
5-MC flight deck announcing system	Too loud	Satisfactory	Satisfactory to difficult	Spotty coverage	Must be very near	Impossible
Type of microphone required	Any	Any	Any microphone satisfactory, including earphone used as mike and bone contact	Any noise-cancelling mike. If earphone used as mike, put under ear protector. If bone contact, under helmet	Good noise-cancelling mikes will reach 125 dB without a noise shield	Noise-cancelling microphone in noise shield
Type of earphone required	Any	Any	Any	Any except bone conductors. Must be in helmet or adequate muff	Insert or over-ear earphones in good helmets or muffs good to 120 dBA on short-term basis	Best insert or over-ear earphones in best helmet or muff, good to 140 dBA on short-term basis

These levels never found in shipboard environment

CHOICE OF COMMUNICATIONS TRANSDUCERS

Comparative charts like table 2, and figures 24 and 25 (adapted from ref. 26), permit the designer of communication equipment to consider factors other than noise levels in choosing acoustic elements for the system he is developing. Not only must the noise levels be categorized into one of the six divisions shown in table 2; but the time pattern of the noise level must be known. In particular, the designer must know how likely it is that a speech message will need to be transmitted or received in the highest levels of noise. For example, before a new flight-deck radio is developed, the probability of requiring communications during the two-finger run-up should be ascertained.

Refer to figures 24 and 25 and note that in noise levels below 90 dBa, ear-insert microphones (doubling as earphones) or bone-contact transducers (for transmitting and receiving) can be used. This would allow a single transducer (with a multiplexing scheme for duplex operation) to be worn and this is not in front of the mouth.

An earmuff or helmet over such a transducer would extend its use up to 110 dBA. Other transducers adequate in levels up to 110 dBA include devices that pick up speech from the teeth, the throat, any bony structure of the head, and from an earphone over, or in, the ear.

It always should be kept in mind that to guarantee a satisfactory speech-to-noise differential at the audio input to any speech-communication

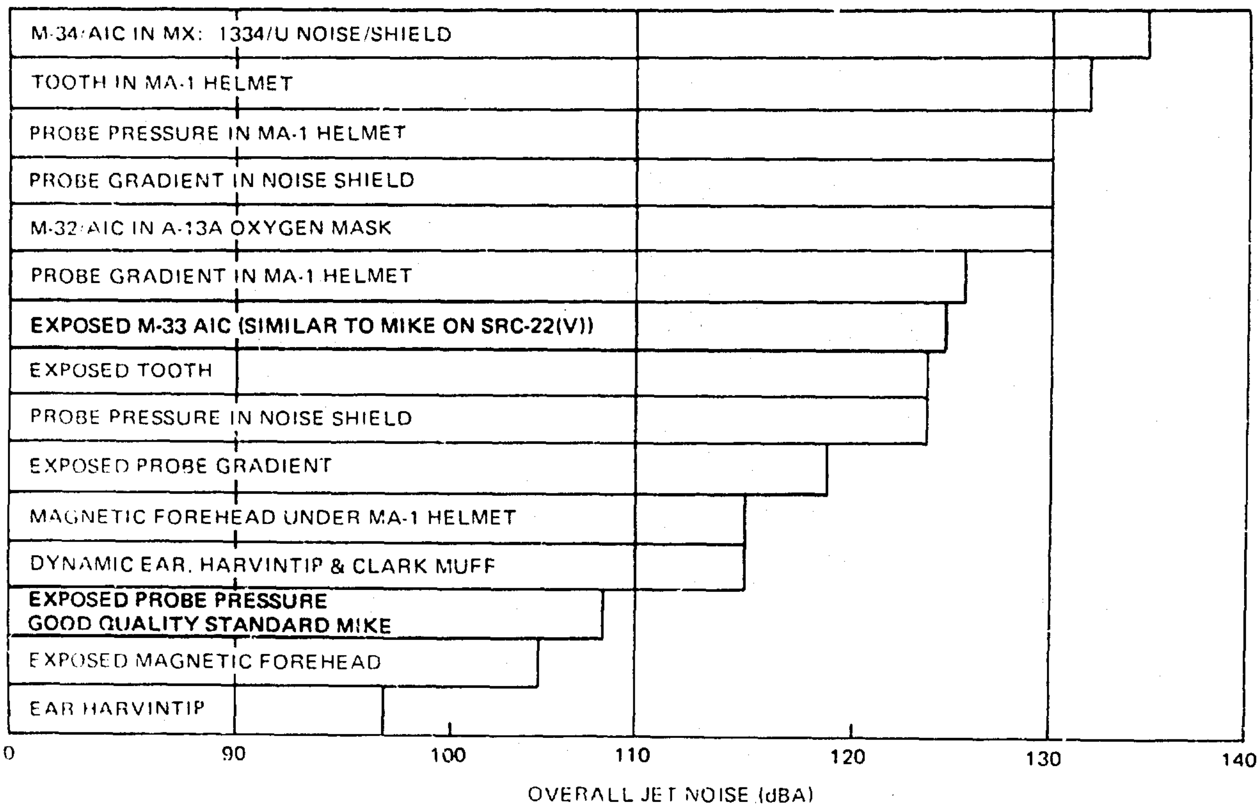

Figure 24. Capabilities of various microphones to operate (transmit speech) in given steady-state noises measured in A-weighted levels. (Adapted from ref. 26.)

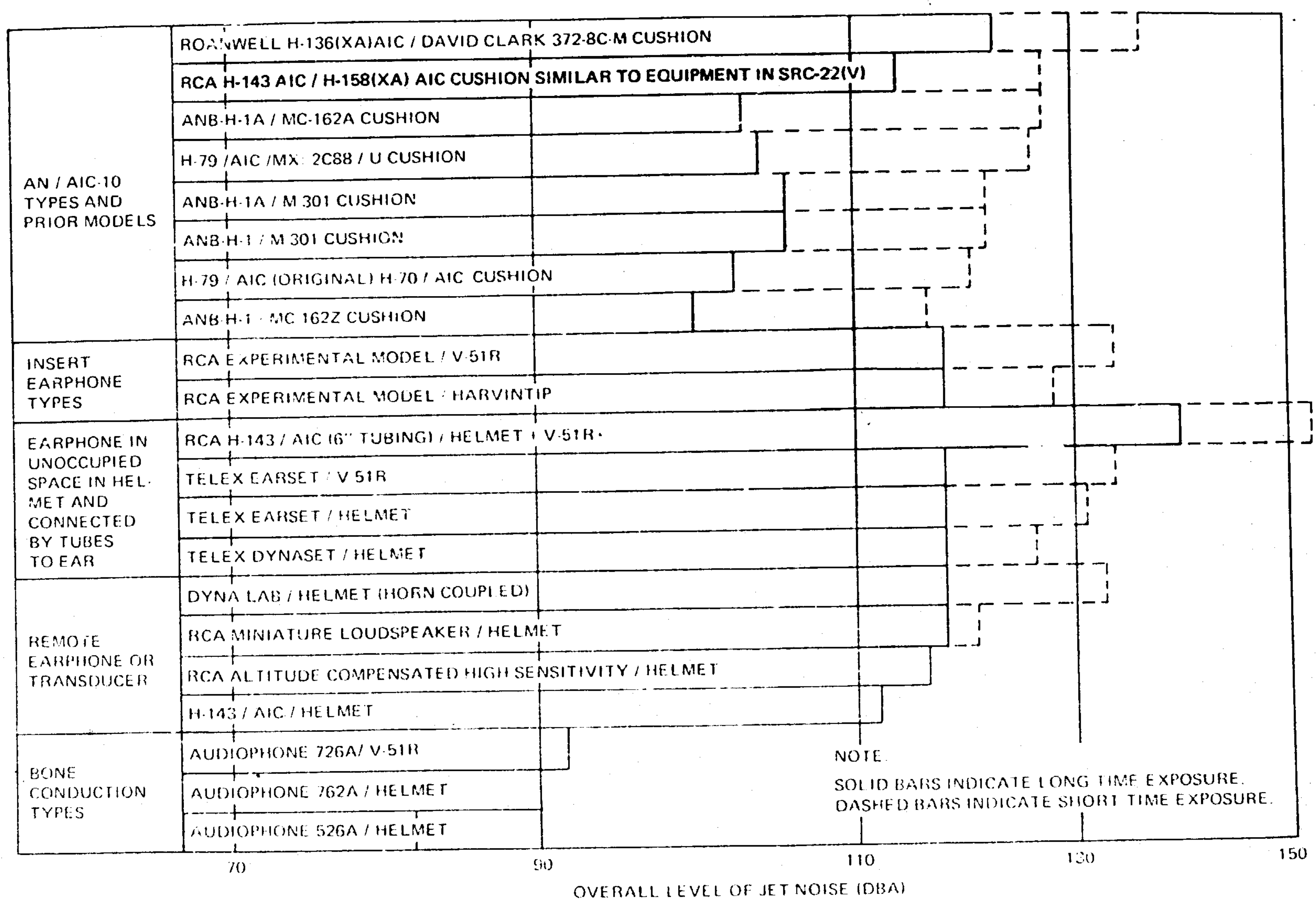

Figure 25. Capabilities of various ear transducers to operate (receive speech) in given steady-state noises measured in A-weighted levels. (Adapted from ref. 21.)

system, the voice signal must be picked up relatively free of the surrounding ambient noise. Speech is obviously most intense directly in front of and almost touching the lips. Therefore, in noise levels above 110 dBA, a noise-canceling microphone just touching the lips should be used. In noise levels above 130 dBA a noise shield must surround the noise-canceling microphone.

The catapult officers, for example, might wear such a shield on their wrist and couple it over the microphone when talking. A more elaborate arrangement might even have a press-to-talk pressure switch on the shield that would activate only when the shield was in firm contact with the chin.

CONCLUSIONS

1. Exposure times of many flight-deck personnel to high-level noise are at or near the damage-risk level. Continuing efforts must be made to maintain and supply hearing protectors as good as or better than those presently in use.

2. The speech-interference level of flight-deck noises drastically reduces effective face-to-face communications for roughly half the time during the 12-hour air operations cycle.

3. Voice announcements over the 5 MC will not be heard by all flight deck personnel when noise levels exceed 110 dB (about 8 percent of the time).

4. Talking and listening on the flight deck over the flight-deck radio during military-power (two-finger) run-ups is severely limited by personnel within 50 feet of the offending aircraft, i.e., when the noise levels exceed about 125 dBA.

5. Data are summarized in charts and figures which show communication designers the capabilities of various acoustic transducers in noise.

AREAS FOR FURTHER INVESTIGATION

The study reported here indicated certain areas where additional work is required, as follows.

1. The effects of wind (knots across the deck) on sound-level meter microphones.

2. The effects of wind-generated noise at the ears and at communication-equipment transducers (affecting the speech intelligibility as transmitted and received).

3. The effects of the jet-blast deflector on the generation, distribution, and directional characteristics of noise on the flight deck.

4. The attenuation actually achieved by the hearing protectors as they are used (or misused) aboard CVA's.

5. Similar noise measurements on A3, F8, E2, and A7 aircraft.

6. More details on noise levels at waist-catapult launching positions (in addition to the bow-catapult positions measured in the work reported here).

RECOMMENDATIONS

1. Insure that sealing rings for the sound-attenuating earmuffs are on board in adequate number to allow prompt replacement of damaged seals and routine replacement at least once a year (or at the start of each deployment).

2. Add, or continue using, a warning phrase to be announced over the 5 MC system before jet engines start, to the effect, ". . . don earmuffs all personnel not wearing ear protectors leave the flight deck . . ."

3. Assign to some DOD activity the permanent task of continually searching for and evaluating better hearing protectors.

4. Institute or continue annual audiometric tests of all flight deck personnel (and pilots).

5. Update the data on the capabilities of current airborne acoustic transducers (microphones and earphones) to give adequate speech-intelligibility scores (75 percent rhyme words correct) in levels of 90, 110, and 130 dBa of jet aircraft noise.

6. Provide a microphone shield for anyone who must talk out when surrounded by noise levels in excess of 125 dBA.

7. Consider issuing "receive only" radios to a large number of flight deck personnel who cannot now hear announcements over the 5 MC flight deck announcing system and who are not equipped with SRC-22(V) flight-deck radios.

8. Either insure that new naval aircraft do not generate noise levels greater than those currently in use, or provide better hearing protection and/or less exposure time for flight-deck personnel.

9. Encourage any study or engineering effort that will reduce the number of personnel required on the flight deck after engines have started.

10. Provide "quiet" crew shelters for flight deck personnel to use between tours of duty on the flight deck and insure that the shelters remain quiet (no high levels of rock and roll music).

11. Conduct programs to pursue the problems listed under "Areas for Further Investigation," in the preceding section.

12. Acquaint designers, administrators, and medical personnel with the hazards inherent in high noise levels during carrier aircraft operations.

REFERENCES

1. Naval Electronics Laboratory Center TN 1789, Acoustical Noise Survey Aboard USS KITTY HAWK (CVA 63), by J. B. Rosenfeld and E. R. Rubin, 17 December 1970 (An informal memorandum intended primarily for use within the Center)

2. Naval Air Test Center, Patuxent River, Maryland, Report ST35-375, Aircraft Noise Emission, Survey of A3J-1 Airplane; Report 6, Interim Report, by R. H. Seltz, 31 August 1961

3. Naval Air Test Center, Patuxent River, Maryland, Report ST35-501, Aircraft Noise Emission, Survey of F4H-1F Airplane; Report 9, Interim Report, by R. H. Seltz, 22 November 1961

4. Naval Air Test Center, Patuxent River, Maryland, Report ST35-167, Aircraft Noise Emission, Survey of A-6A Airplane; Report 14, Interim Report, by C. F. Abell, 15 April 1963

5. Naval Air Test Center, Patuxent River, Maryland, Report ST35-166, Aircraft Noise Emission, Survey of A-4E Airplane; Report 13, Interim Report, by C. F. Abell, 15 April 1963

6. Young, R. W. and Peterson, A., "On Estimating Noisiness of Aircraft Sounds," Acoustical Society of America. Journal, v.45, p. 834-838, April 1969

7. Navy Electronics Laboratory Report 1314, Speech Interference Aspects of Navy Noises, by J. C. Webster and R. G. Klumpp, 2 September 1965

8. Webster, J. C., "Effects of Noise on Speech Intelligibility," p. 49-73 in National Conference on Noise as a Public Health Hazard. Proceedings, 13-14 June 1968, The American Speech and Hearing Association, 1969 (ASHA Report 4)

9. Webster, J. C. and Gales, R. S., "Noise Rating Methods For Predicting Speech Communication Effectiveness," p. 85-102 in Symposium on Evaluating the Noises of Transportation, 1969, Transportation Noises; A Symposium on Acceptability Criteria, Edited by J. D. Chapulnik, University of Washington Press, 1970

10. Brüel, P. V., "Aerodynamically Induced Noise of Microphones and Windscreens," Brüel & Kjaer Technical Review, No. 2, p. 3-26, 1960

11. Hayes, J. R. M. and Cudworth, A. L., "A Windscreen For the Ear," Acoustical Society of America. Journal, v. 26, p. 254-255, March 1954

12. Harvard University, Psycho Acoustical Laboratory Report PNR-133, Problems of High-Intensity Noise: A Survey and Recommendations, by W. A. Rosenblith and others, 30 December 1952

13. Kryter, K. D. and others, "Hazardous Exposure to Intermittent and Steady-State Noise," Acoustical Society of America. Journal, v. 39, p. 451-464, March 1966

14. Botsford, J. H., "Simple Method For Identifying Acceptable Noise Exposures," Acoustical Society of America. Journal, v. 42, p. 810-819, October 1967

15. Intersociety Committee, "Guidelines For Noise Exposure Control," Sound and Vibration, v. 4, p. 21-24, November 1970

16. Webster, J. C. and Lepor, M., "Noise, You Can Get Used to It," Acoustical Society of America. Journal, v. 45, p. 751-757, March 1969

17. Naval Electronics Laboratory Center TD 67, Objective and Subjective Noise Level Survey on U.S.S. MARS (AFS 1), by J. C. Webster, F. G. Henry, and W. Kreysler, 13 October 1969

18. Webster, J. C. and Rubin, E. R., "Noise Attenuation of Ear-Protective Devices," Sound, v. 1, no. 5, 1962, p. 34-46, figs. 2, 3, 14, and 15

19. Beranek, L. L., Acoustics, McGraw-Hill, 1954

20. Webster, J. C., "Speech Communications as Limited by Ambient Noise," Acoustical Society of America. Journal, v. 37, p. 692-699, April 1965

21. Klumpp, R. G. and Webster, J. C., "Physical Measurements of Equally Speech-Interfering Navy Noises," Acoustical Society of America. Journal, v. 35, p. 1328-1338, September 1963

22. Aerospace Medical Research Laboratories TDR 64-67, Speech Intelligibility Evaluation of Four Noise-Canceling Microphones, by C. W. Nixon and H. C. Sommer, December 1964

23. Navy Electronics Laboratory Report 977, A Comparison of Five Intelligibility Tests for Voice Communication Systems, by W. E. Montague, 27 June 1960

24. Kryter, K. D. and others, "Speech Communication," Chapter 4 in Human Engineering Guide to Equipment Design, C. T. Morgan, ed., McGraw-Hill, 1963

25. Beranek, L. L., "Revised Criteria For Noise in Buildings," Noise Control, v. 3, p. 19-27, January 1957

26. Western Electro-Acoustic Laboratory, Incorporated, Contract AF33(616)-3710; Phase 2, Final Report, Study and Investigation of Specialized Electro-Acoustic Transducers for Voice Communication in Aircraft, January 1960

27. Webster, J. C., "Speech Intelligibility in Noisy Environments," Paper 4 in North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development Advisory Report 19, Aeromedical Aspects of Radio Communication and Flight Safety, December 1969

NELC PHOTOGRAPHS

Illustration No.	NELC Photograph No.
1A	N2848
2A	LSF 3468-12-69
2B	LSF 3492-12-69
3	LSF 3470-12-69
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4B	LSF 3473-12-69
5	LSF 3477-12-69
6	LSF 3493-12-69

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APPENDIX: SIL — PAST, PRESENT, AND FUTURE

(Reprinted from Sound and Vibration, Vol. 3, No. 8, 22-26, 1969)

NAVAL ELECTRONICS LABORATORY CENTER

San Diego, California 92152

30 April 1971

Naval Electronics Laboratory Center Technical Report 1762. Noise Levels on Aircraft-Carrier Flight Decks, and Their Effects, by J. C. Webster, 30 April 1971

Note regarding APPENDIX: SIL – PAST, PRESENT, AND FUTURE (reprinted from Sound and Vibration, Vol. 3, No. 8, 22-26, 1969)

The Appendix has been included in copies of TR 1762 addressed to recipients who have a special interest in the measurement of speech-interference levels and who may not have read the article previously. For the general reader, SIL measurements are treated in sufficient detail in the main text to describe the methods involved in gathering the data reported.

Recipients wishing a copy of the reprint may address a request for it to the Naval Electronics Laboratory Center.

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SIL—PAST, PRESENT, AND FUTURE

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The speech-interfering aspects of noise can be specified in terms of the level and spectrum of speech and noise at the listener's ear. A recommended procedure is based on the PSIL (average of the octave-band levels centered at 500, 1000, and 2000 Hz) or A-weighted sound level and the distance between communicators. A nomograph simplifies the application of the technique.

THE MEASURE OF NOISE known as the speech-interference level (SIL) has been, and still is, a useful engineering tool for noise control. As originally conceived by Beranek[1] and applied to sound control in airplanes by Beranek and Rudmose,[2] the measure was based on the concepts developed by French and Steinberg[3] for the articulation index (AI). As stated by Beranek,[4] ". . . if we desire to divide the frequency scale into three bands of equal contribution to speech intelligibility, using available analyzing equipment, we should divide it into the frequency ranges 300 to 1200 cps, 1200 to 2400 cps, and 2400 to 4800 cps. However, because the articulation-index frequency scale is more nearly linear below 1000 cps than logarithmic . . . , an intensity average in the 300- to 1200-cps band is not correct. Moreover, usual available analyzing equipment includes the bands 300 to 600, 600 to 1200, 1200 to 2400 and 2400 to 4800 cps.

"To a sufficiently close approximation, we can, if the level in the 300- to 600-cps band is not more than 10 dB above that in the 600- to 1200-cps band, use the 600- to 1200-cps band as the first band and then define the speech-interference level as the arithmetic average of the sound pressure levels in the three bands 600 to 1200, 1200 to 2400, and 2400 to 4800 cps. However, if the levels in the 300- to 600-cps band are more than 10 dB above those in the 600- to 1200-cps band, the average of the levels in the four bands between 300 and 4800 cps should be used instead."

He continues: "If the levels of . . . speech are also known . . ., an estimate can be made of the articulation index. . . ."

If the exact levels of speech are not known, but ". . . two men are . . . facing each other in [the same] noise field, the maximum speech-interference levels that just permit reliable communication at various voice levels and distances are . . . shown in [a] Table . In making up this table, average male voices and good hearing are assumed, as well as unexpected word material. If the vocabulary is limited or if sentences only are spoken, the permissible speech-interference levels may be increased by about 5 dB. If a woman is speaking, the permissible levels should be decreased by about 5 dB."

The SIL must have been a good engineering tool from the beginning, because Beranek (as originally published by Beranek *et al.*[5] soon devised ways of estimating it from sets of frequency-weighted speech communication (SC) contours. These contours were subsequently modified to the more familiar noise criteria (NC) and alternate NC (NCA) contours.[6,7]

Beranek then validated the SIL measure, supplemented by loudness level (LL) measures (originally developed by Stevens[8] and modified by him at the present time through six revisions[9]), to establish criteria for rating acceptable noise levels for offices.

At about this same time Young[10] started propounding the virtues of the A-weighting scale of the sound level meter as measure of noise relating to the subjective responses of people to noise. In his first forays, Young noted that the A-weighted level gave good approximations to loudness level, as well it should, since the A-weighting network was modeled on the 40-phon loudness level contour. Young[11] later pointed out that the average decibel reading at octaves centered at 500, 1000, and 2000 Hz is well estimated by the A-weighted level [unless there is a preponderance of noise energy in the octaves above 2000 Hz, and this is *not* characteristic of most office or industrial noises]. Obviously to the extent that the A-weighted level approaches an average reading for three octaves of noise centered around 1000 Hz, it would estimate SIL.

On another tack, Kryter,[12] using matching techniques, developed a "perceived" noise level that correlated with the annoying properties of, in particular, jet aircraft noise. Like loudness level (LL), to which perceived noise level (PNL) closely corresponds, many revisions in calculation procedures and applications followed. These have resulted in an updated summary paper on PNL by Kryter[13] which relates SIL (as estimated by NC contours), the A-weighted level, and effective PNL as limiting noise levels for various types of rooms.

Any one of the measures of noise discussed above, and variations of them, can and have been used to predict the speech-interfering aspects of noise. For example, Kryter and Williams[14] correlated intelligibility scores on modified rhyme words (developed by House *et al.*[15]) against six noise measurements of fourteen different aircraft noises (six different aircraft, some performing as many as three evolutions: run-ups, landings, and takeoffs). All but two of these noises had relatively flat spectra over the speech range (300 to 4800 Hz), and only five had any greater amounts of energy below 300 Hz. They found that the "differences between dB(A), NC, SIL, and PNdB are probably not significant."

Williams *et al.*,[16] also using modified rhyme words,

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Contours		SLM		PNdB	SIL	PSIL	AI
NCA	25(5.2)*,†,**	L_C	26.5(7.4)	20(5.2)*,†	(600-1200, 1200-2400, 2400-4800 Hz octaves)		16.6(4.8)*,**
ISO(R)	19(4.8)†	L_A	18.5(4.7)*,†,**		(300-600, 600-1200, 1200-2400 Hz octaves)		9.7(2.5)†
SI	14(3.7)‡	SI	10.0(3.0)‡		(500, 1000, 2000 Hz octaves)		10.5(2.8)‡
					AI		8.1(2.4)

* Kryter and Williams.[11] Measures not different. SIL (300-600, 600-1200, 1200-2400 Hz octaves) not measured.

** Williams, et al.[16] Measures not different, SIL (300-600, 600-1200, 1200-2400 Hz octaves) not measured.

† Young.[11] Correlation -0.91, SIL 0.86 (600-1200, 1200-2400, 2400-4800 Hz octaves).

‡ Suggested new measures.

Table I - Summary of major experimental results in terms of range and standard deviation in dB.

aircraft noise (flyover, *not* steady state), and measures of dBA, PNL, AI, and SIL, found again that "the differences among the various correlations are probably not significant."

Young[11] found correlations of 0.91 or greater between dBA, PNL, SIL (300 to 2400 Hz), and the noise rating originally arrived at by Beranek[6] for his seventeen office noises. The noise rating was *not* based entirely on speech interference, but office noise acceptability certainly includes the ability to converse.

The most comprehensive study in terms of diverse noise spectra and the variety of noise measures used was by Klumpp and Webster.[1] They had eight listeners adjust the levels of sixteen quasi-steady-state noises to mask out 50% of Fairbanks' [18] rhyme words played to them via a loudspeaker (3 feet directly in front of them) at a level of [illegible]. They then measured the level of each noise by thirteen different methods and calculated the standard deviation for each of the thirteen measures over each of the sixteen (equally speech-interfering) noises. Obviously, the measure with the smallest standard deviation was the best measure of the speech-interfering aspects of the sixteen noises. Table I shows a summary of the range and standard deviations of some of the better and or more common noise measurement methods. Four classes of measurement methods are shown: those based on matching octave band noise spectra to noise-rating "contours" (peak fitting method); sound level meter (SLM) readings (integration method); perceived noise level in dB (PNdB); and averaging methods, SIL (based on the different octaves shown) and the articulation index (AI). Note that the measures considered to be equivalent by Kryter and Williams,[11] Williams *et al.*, [16] and Young[11] are marked. The suggested new measures include a new set of speech interference (SI) contours (Webster[19, 20]), a new speech-interference (SI) weighting network,[21, 22] and an SIL based on octaves centered at 500, 1000, and 2000 Hz (the so-called preferred frequency SIL, or PSIL).

The results summarized in Table I show that, for aircraft noises, SIL, PNL, dBA,[11] and AI [16] give generally equivalent measures of speech interference. For office noises, SIL, PNL, dBA, NC, and LL give generally equivalent evaluations of acceptability.[11] For diverse spectra noises, the preferred frequency SIL (PSIL) is probably the best compromise, simple measure of speech interference with dBA, SIL (600 to 4800 Hz), NCA, and PNL being generally equivalent but showing greater variability with spectra.

It is important to note that, although any one of the above measures gives a fair approximation to the speech-interfering properties of noise, the actual values for each measure averaged over many noise spectra are considerably different. Table II shows how these absolute values differ for each of five noise measures over four different samplings of noise. Note that PNL always has the greatest numerical value, followed by C-weighting, A-weighting, PSIL, and SIL. The column labeled Av is the average difference over all noise samples and is the best guess at present for how to estimate what all other

measures are if you know just one. The last column (S.D.) is the value of the standard deviation, taken from Table I. It shows the variation of the particular measure over sixteen noises with very diverse spectra. On any sample of similar noises—office, industrial, traffic, or aircraft—the variation would be less.

A New Procedure

Since PSIL shows the smallest expected variability over diverse spectra noise and the A-weighted level is the simplest to measure, these are the recommended measures for assessing the speech-interfering aspects of noise. Figure 1 shows how to interpret these levels of noise in terms of voice level and distance between a talker and a listener. This figure is merely a graphical elaboration of the table first introduced by Beranek[1] to interpret distance and required voice level for given levels of SIL. See the limitations listed above in the quotation from Beranek,[4] so they apply here as well. There are two innovations which should make this graph more useful than the old Beranek table—the "expected voice level" and the "communicating voice level" lines. These lines result from the fact that in noise people tend to increase their vocal effort or raise their voice level (called the Lombard voice reflex). Kryter,[23] Korn,[24] and Pickett[25] agree that male talkers, at least, raise their voices 3 dB for each 10-dB increase in the surrounding noise level at levels starting at about 50 dB PSIL. This is the amount of increase in vocal effort when there is no feedback to the talker of how effective his communications are. It is his "expected voice level" increase in noise.

Webster and Klumpp[26] made their talkers really communicate (95% word scores with positive and instantaneous feedback of success or failure). Their "communicating" talkers raised their voice level 5 dB for every 10 dB increase in noise.

Pickett[27] and a Western Electro-Acoustic Laboratory Report[28] show that the total vocal effort range is 44 dB (WEAL) to 50 dB (Pickett), but the useful range is closer to 35 dB. That is, the last 10 dB of effort does not result in increased intelligibility. These are the data used to divide the "difficult" from the "impossible" region on the right of the figure.

To interpret the figure, note that to converse in a normal voice at 6 feet a PSIL of about 53 dB or an A-weighted level of 60 dBA could be tolerated. (This corresponds to an old SIL of 50 dB.) Above this noise level a normal voice level would never be expected of normal-hearing people; they would raise their voice level according to the "expected voice level" line.

As another example, let us say we wish to know how noisy a space can be to allow people to converse at 3 feet. An extension of the 3-foot distance line to the "expected voice level" line dictates an upper noise level limit of about 65 dB PSIL or 72 dBA.

In general, this "human engineering nomograph" can be used only if the same noise surrounds both the talker and the listener. However, let us say that an 80-dB PSIL noise surrounds only the talker. At this level his vocal effort would be expected to be between "raised" and "very loud," and as such he could be heard by a listener in the same noise, 80 dB PSIL, at 1 foot, but by a listener in 70 dB PSIL at over 2 feet, or at 8 feet if the listener were in 60 dB PSIL of noise.

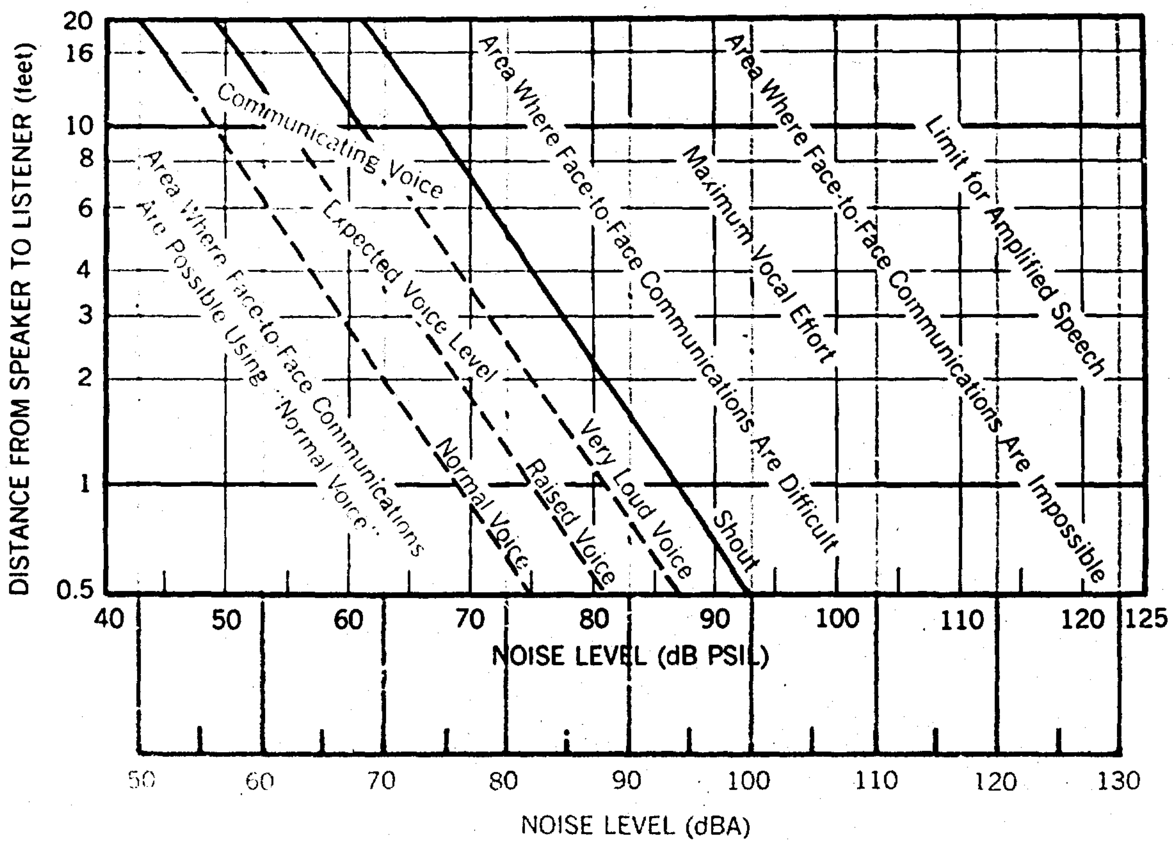
Summary

To summarize the past and present of specifying the speech-interfering aspects of noise: Speech com-

	1	2	3	4	Av	S.D.
PSIL	0	0	0	0	0	2.8
SIL	—4	—2	—3	—2	—3	4.8
L_A	6	9	4	10	7	4.7
PNL	19	22	16	22	20	5.2
L_C	17	16	8	13	14	7.4

1. Beranek,[6] seventeen office noises.
2. Kryter and Williams,[14] fourteen aircraft noises.
3. Williams et al.,[16] nineteen flyover noises.
4. Klumpp and Webster,[17] sixteen equally diverse speech-interfering noises.

Table II — Relative noise levels among various measurement methods for different noise samples.



... Voice level and distance between talker and listener for satisfactory face-to-face speech communications ... ambient noise level. Along the abscissa are two generally equivalent objective measures of noise ... band level in the octaves centered at 500, 1000, and 2000 Hz, called the three-band ... speech interference level (PSIL), and the A-weighted sound level meter reading (dBA). Other ... be used by applying the constant correction listed in Table II. The relative reliability of all common ... shown in Table I. An example for interpreting the chart: Jet aircraft cabin noise is roughly 80 ± 2 ... dBA in their expected (raised) voice level, seatmates can converse at 2 feet and by moving a little, ... to normal level and converse at one foot. To ask the stewardess for an extra cup of coffee ... one would need to use his communicating (very loud) voice.

... are limited by the level and spectrum ... by the level and spectrum ... the speech at the ear of the listener. ... AI from alpha to omega, see ... Kryter ... considers all ... the spectral and level aspects ... The speech-interference ... considers only the ... of the noise and refers to ... limiting levels of ... level and ... Other tables ... acceptability. The ... averaging octave pressure levels from 300 or 600 Hz to 4800 Hz, was based on the AI rationale. The newer PSIL, based on octaves centered at 500, 1000, and 2000 Hz, was developed from a comparison among many known methods of measuring equally speech-interfering noises[7] and relating these to the extensive validation studies of the older SIL.[6,7,11] The new PSIL will soon be proposed as a new USASI standard to bring SIL into line with the preferred frequency method of measuring noise.

Other objective noise measures that correlate with subjective responses to noise such as loudness level (LL),[2] perceived noise level (PNL),[12,13] and A-weighted level[10] were shown to be highly corre-

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lated with SIL.[11, 14, 16, 17, 21]

It is proposed that PSIL (and estimates of it by A-weighted level) replace SIL as the best method of estimating, by means of Figure 1, the speech-interfering aspects of noise. Other estimates of PSIL including SIL, PNL, and C-weighting are listed in Table II, along with an estimate of expected error over diverse spectra noises.

The future of PSIL will depend on how well it aids engineers, architects, and designers in specifying limiting noise levels for various spaces. The older specifications developed by Beranek[6, 7] are not invalidated by the newer PSIL. To convert from SIL to PSIL, just add 3 dB to the old SILs and call them PSILs. This correction will be adequate if office noises of the future are like the seventeen used by Beranek to establish the existing tables—that is, if the level of noise in the 300- to 600-Hz octave is 4 or 5 dB greater than the level in the 600 to 1200-Hz octave.

Based on the PSIL nomograph (Figure 1) and the assumption that communication at 3 feet is acceptable for communicating areas in ships, a specification of 64 to 65 dB PSIL or 71 to 72 dBA has been proposed. Webster and Lepor[32] have shown that 80% of the people on USN ships do indeed feel that levels up to 3 dB greater than the 64 to 65 dB PSIL specification is "acceptable" and that "normal speech" is not affected.

The slope of the "expected" and "communicating" voice level lines and the boundary between "difficult" and "impossible" communications (now developed from laboratory studies) may have to be modified slightly from future applied or field results. As of this date, however, Figure 1 is proposed as a simple method of evaluating the speech-interfering aspects of noise.

References

1. L. L. Beranek, Airplane Quieting II—Specification of Acceptable Noise Levels, *Trans ASME*, 69, 96-100 (1947).
2. L. L. Beranek, and H. W. Rudmose, Sound Control in Airplanes, *J. Acoust. Soc. Am.* 19, 357-364 (1947).
3. N. R. French, and J. C. Steinberg, Factors Governing the Intelligibility of Speech Sounds, *J. Acoust. Soc. Am.* 19, 90-119 (1947).
4. L. L. Beranek, *Acoustics*, McGraw-Hill Book Company, New York, 1954.
5. L. L. Beranek, J. L. Reynolds, and K. E. Wilson, Apparatus and Procedures for Predicting Ventilation System Noise, *J. Acoust. Soc. Am.* 25, 313-321 (1953).
6. L. L. Beranek, Criteria for Office Quieting Based on Questionnaire Rating Studies, *J. Acoust. Soc. Am.* 28, 833-852 (1956).
7. L. L. Beranek, Revised Criteria for Noise in Buildings, *Noise Control* 3, No. 1, 19-27 (1957).
8. S. S. Stevens, Calculation of the Loudness of Complex Noise, *J. Acoust. Soc. Am.* 28, 807-832 (1956).
9. S. S. Stevens, Procedures for Calculating Loudness, Mark VI, *J. Acoust. Soc. Am.* 33, 1577-1585 (1961).
10. R. W. Young, Don't Forget the Simple Sound-Level-Meter, *Noise Control* 4, No. 3, 42-43 (1958).
11. R. W. Young, Single Number Criteria for Room Noise, *J. Acoust. Soc. Am.* 36, 289-295 (1964).
12. K. D. Kryter, Scaling Human Reactions to the Sound from Aircraft, *J. Acoust. Soc. Am.* 31, 1415-1429 (1959).
13. K. D. Kryter, Concepts of Perceived Noisiness, Their Implementation and Application, *J. Acoust. Soc. Am.* 43, 344-361 (1968).
14. K. D. Kryter, and C. E. Williams, Masking of Speech by Aircraft Noise, *J. Acoust. Soc. Am.* 39, 138-150 (1966).
15. A. S. House, C. E. Williams, M. H. L. Hecker, and K. D. Kryter, Articulation-Testing Methods: Consonantal Differentiation with a Closed Response Set, *J. Acoust. Soc. Am.* 37, 158-166 (1965).
16. C. E. Williams, K. N. Stevens, M. H. L. Hecker, and K. S. Pearsons, The Speech Interference Effects of Aircraft Noise, Federal Aviation Administration Report DS-67-19 (1967).
17. R. G. Klumpp and J. C. Webster, Physical Measurements of Equally Speech-Interfering Navy Noises, *J. Acoust. Soc. Am.* 35, 1328-1338 (1963).
18. G. Fairbanks, Test of Phonemic Differentiation: The Rhyme Test, *J. Acoust. Soc. Am.* 30, 596-600 (1958).
19. J. C. Webster, Generalized Speech Interference Contours, *J. Speech & Hearing Res.* 7, 133-140 (1964).
20. J. C. Webster, Relations between Speech-Interference Contours & Idealized Articulation Index Contours, *J. Acoust. Soc. Am.* 36, 1662-1669 (1964).
21. J. C. Webster, and R. G. Klumpp, Speech Interfering Aspects of Navy Noises, U. S. Navy Electronic Laboratory Report 1314 (1965). (See especially section VII).
22. J. C. Webster, Frequency Weighting Contours for Predicting the Speech Interfering Aspects of Noise, Philosophical Transactions of the Royal Society of London, A. Vol. 263, 315-323 (1968).
23. K. D. Kryter, Effects of Ear Protective Devices on the Intelligibility of Speech in Noise, *J. Acoust. Soc. Am.* 18, 413-417 (1946).
24. T. S. Korn, Effect of Psychological Feedback on Conversational Noise Reduction in Rooms, *J. Acoust. Soc. Am.* 36, 793-794 (1954).
25. J. M. Pickett, Limits of Direct Speech Communication in Noise, *J. Acoust. Soc. Am.* 30, 278-281 (1958).
26. J. C. Webster, and R. G. Klumpp, Effects of Ambient Noise and Nearby Talkers on a Face-to-Face Communication Task, *J. Acoust. Soc. Am.* 34, 936-941 (1962).
27. J. M. Pickett, Effects of Vocal Force on the Intelligibility of Speech Sounds, *J. Acoust. Soc. Am.* 28, 902-905 (1956).
28. Study and Investigation of Specialized Electro-Acoustic Transducers for Voice Communication, Western Electro Acoustics [illegible] Rep. [illegible] No. AF 33 [illegible] 210, Task No. 14004 [illegible]
29. K. D. Kryter, Methods for the Calculation and Use of the Articulation Index, *J. Acoust. Soc. Am.* 34, 1689-[illegible]
30. K. D. Kryter, Validation of the Articulation Index, *J. Acoust. Soc. Am.* 34, 1698-1702 (1962).
31. J. C. Webster, [illegible] Noise on Speech Intelligibility [illegible] Noise [illegible] Conference on Noise as a [illegible] H [illegible] 1968, The [illegible] ASHA Reports [illegible]
32. J. C. Webster [illegible] 45 [illegible]

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